Optimising Production Control for Reduction of Allergen Contamination

A Thesis by

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Abstract

The purpose of this work was to provide an integrated solution to the problem of optimising plant production flow while also optimising allergen control. That is, to improve process flows, improve equipment utilisation, reduce work-in-process (WIP) inventory, and reduce unnecessary movement of stock while also optimising allergen control in the area under investigation.

Process improvement introduced to the plant during the project resulted in a 7% savings on labour cost, reduction in plant variability, reduced allergen cross contamination risk, reduced WIP, reduction of consumables, and increased equipment utilisation.

Discrete event simulation software has been used to determine the preferred strategy for implementing allergen control in a food producing FMCG plant. Three preferred allergen control strategies were identified by the Company, which were then modelled and analysed for impact on labour cost. Furthermore, a study was done on the effect of plant layout on labour cost.

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Dedication

For Sunshine.

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Chapter 1
Introduction

1.1 What is FMCG?

FMCG are consumer packaged goods that are sold in large volumes, are being sold quickly, and are sold with a relatively low profit margin. Another characteristic of FMCG is that its life cycle can be relatively short – a few months – if the product proves to be unpopular with consumers. Typical FMCG products are meat and fish products, dairy products, bakery products, soap and detergents, and toiletries. The FMCG manufactures operate in a market exposed to seasonality and continuously changing consumer preferences.

1.2 The productivity issues in FMCG manufacturing

Compared to conventional engineering products, FMCG pose some special challenges for production engineers. FMCG plants manufacture goods for direct consumer end-use, and therefore the FMCG plant will have to be able to cope with fluctuating demand and an ever changing product mix. The plant needs to be flexible to be able to cope with fluctuating demand, while being robust enough to assure maximised efficiency for a changing product mix.

For production purposes, products are typically grouped into a product family based on a shared generic quality. Product diversity is augmented by taking the generic quality of a product and adding additional qualities such as flavour, scent, or colour. Usually a product family is produced on a single process line. But, with several product families being manufactured in the same plant, the process lines are likely to share resources and equipment. In the case of a food processing FMCG plant, the sharing of equipment puts the added constraint of allergen control on production. Allergen cross-contamination issues may arise when residue from earlier produced product on a production line is picked up by product produced on that same production line later on.

Allergen control is rapidly becoming an area of greater importance for food manufacturers. Food Standards Australia New Zealand (FSANZ) states that undeclared allergens were the number one reason for food product recalls in 2013 (Figure 1).

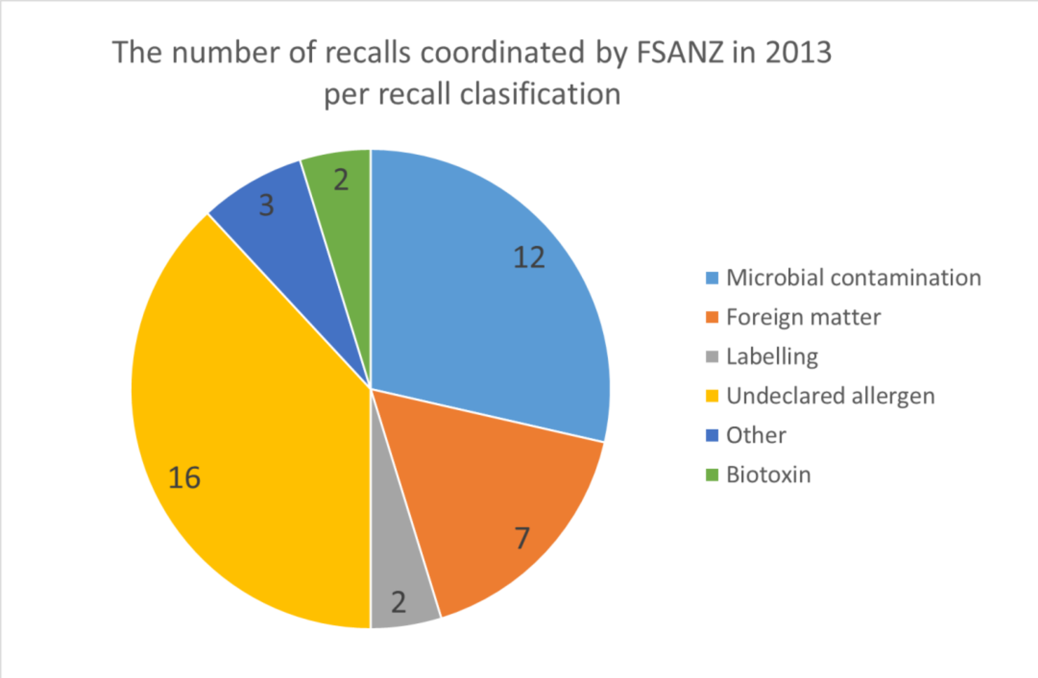


Figure 1. Number of recalls coordinated by FSANZ in 2013 (source: FSANZ[1])

In order to make sound judgement as where to direct improvement efforts in a food processing FMCG plant, a company will need to take into consideration short term product volume and product mix, but also long term product volume and product mix. Long term forecasting data for product volume and product mix might be available, and could give an indication as to where to direct improvement efforts, but often such data is lacking. In practice, when reliable forecasting data is not available, management relies on a bottom-up approach with regards to process improvement efforts. That is, it expects production staff to initiate the improvements efforts. Understandably, a bottom-up approach may lead to staff trying to maintain the status qua, followed by ad-hoc changes to the production processes. Not only may changes be ad-hoc, in addition, staff may not have much appreciation for additional constraints that add complexity to the problem, such as allergen control.

1.3 Industrial context

This project was contextualised in a research collaboration with Tegel Foods Ltd. Tegel is an FMCG manufacturer which main line of business is processing chicken-meat. The value added (VA) plant at Tegel is comprised of multiple process lines where additional work is done on chicken-meat to produce more than 80 different products. Additional work can be, for example, spicing the meat, skewering it,

[1] http://www.foodstandards.govt.nz/industry/foodrecalls/recallstats/Pages/default.aspx

and then wrapping it. In total there are about 10 distinct processes in the VA plant. Customer demand for the products fluctuates significantly, and out of the 80 products only 7 have more than a 100 kg average daily volume. Tegel has seen an increase in business in VA and wanted to improve process flows to reduce process inventory and unnecessary movement of stock. The movement of stock within the plant required plastic liner in order to avoid allergen cross-contamination. The liner was used only once and then discarded. Every year $26,000.00 was spent on plastic liner alone: not including the labour involved. Besides the fluctuating demand and the number of different products, the VA processes were further complicated by the need for allergen control and the limited amount of available floor space. An attempt had been made by Tegel to improve efficiency in the VA plant but thus far had not been able to find an appropriate solution. The problem was complex because of the combination of product mix, fluctuating volumes/demand for each, the need for allergen control, the physical constraints of the existing plant, and a team of operators that was vehemently opposed to change.

The purpose of this project was to provide an integrated solution to the problem of optimising plant production flow while also optimising allergen control. That is, to improve process flows, improve equipment utilisation, reduce work-in-process (WIP) inventory, and reduce unnecessary movement of stock while also optimising allergen control in the plant under investigation. This thesis attempts to address this problem by using Lean methodologies and discrete event simulation.

Chapter 2
Literature review

2.1 Production Improvement

In the introduction to his in 1919 published seminal book *The Principles of Scientific Management* Frederic Winslow Taylor, the founder of scientific management, laments that: “In the past man has been first; in the future the system must be first” [1]. According to Taylor, in order to increase efficiency, the focus is to be no longer on manipulating employees, but on manipulating systems. Probably the most famous example of a manipulated system from Taylor’s days would have to be the Ford Motor Company assembly line. Taylor and Ford’s men, not unlike Newton and Leibniz, arrived at the same conclusion independently and unbeknownst to each other [2]. But, much like Newton and Leibniz, their work also changed human society in a way that can hardly be overstated.

In 1930 Walter A. Shewhart published his famous paper *Economic Quality Control of Manufactured Product* [3]. In this paper efficiency was made a function of quality. The paper presented a scientific basis for determining when it is no longer economically feasible to eliminate unknown causes of variability in the quality of a product: a scientific tool was devised to manipulate systems in an economical fashion - in effect making Dr. Shewhart the originator of statistical process control (SPC). After WWII W. Edwards Deming, a student of Dr Shewhart, taught SPC to Japanese managers and engineers [4]. Over time SPC, the teachings of Henry Ford, and other production techniques morphed into the Toyota production system (TPS). While the Ford Motor Company assembly line is best known for efficiently mass producing a single product, a model T for example, in contrast, the predominant feature of TPS is the ability to efficiently produce large variety in small volumes [5]. In 1978 Ohno published his book *Toyota Production System* (in Japanese) in which he gave an account on how he manipulated the production system at Toyota to produce more efficiently. 1978 was also the year in which a study was published concerning productivity in the motor industry: UK, American, and European manufactures were included, Japanese manufactures were not [6]. It is telling though that in a study published only five years later, in 1983, not only were Japanese manufactures included: they were leading the pack with regards to productivity [7]. So, how was this made possible? Was it circumstance, or was it that the TPS was a superior manufacturing technique?

The main objective of the TPS is to eliminate waste (termed Muda in Japanese) from work procedures and work hours whilst designing out unreasonableness (Muri) and inconsistency (Mura). Muda, the non-value adding activities within a process, can be further categorized into seven wastes [5]. These wastes are:

1) Overproduction
2) Waiting
3) Transporting
4) Too much machining (over-processing)
5) Inventories
6) Moving
7) Making defective parts and products

The method deployed to combat Muda is just-in-time (JIT) manufacturing, and the operational tool used is Kanban (more on these later) [5]. A consistent flow of product throughout the plant is a requirement for JIT to work: no peaks and valleys of work. That is, the work must be leveled in order to be able to design out Mura [8]. Also, while a focus on system as opposed to man might suggest otherwise, the TPS, right from it's onset, focused on designing out Muri by means of allowing workers to display in full their capabilities through active participation in running and improving their own workshops [9].

In 1982 W. Edwards Deming, in an effort to divert impending doom for American manufacturers, published his book *Quality, Productivity, and Competitive Position*. In this book he confirmed that the performance of a system is mainly governed by the design of that same system, and that people working within, and interacting with, that particular system are only accountable for a fraction of the total accrued loss of efficiency [10]. During this same decade several books on TPS were published but these were mainly written for a technical audience and went basically unnoticed [5, 8, 11-13]. It was not until the publication of *The Machine that changed the World* by Womack et al. in 1990 that a large audience is reached: an audience that was ready to receive the message that Japanese competitive advantage is *not* due to circumstance but due to superior production techniques [14].

Although literature on the TPS had been published, none of these used the term 'Lean'. It was not until *'Machine'* that the term Lean came to be popularized. So how was TPS transformed into Lean? The simple answer: only the name changed. In an effort by researchers to capture the difference between a large-variety/small-volumes production facility on one side of the spectrum and a mass-production facility on the other side, companies were classified as 'fragile', 'robust', or 'buffered'. Initially it was *this* terminology that was used as a benchmarking index. Later 'fragile' was amended to 'Lean', which was seen to have a more positive connotation [14]. So, by the time 'Machine' was introduced to the public, researchers would refer to a company that would deploy the TPS as being a Lean company, that is, a company that was using a Lean production system.

In order to turn a production system into a Lean production system the Lean practitioner can resort to a variety of Lean tools and techniques. While the list of tools and techniques include those that were initially used in the TPS, over time, others have been added. A summary and review of Lean tools and techniques is provided below. The tools and techniques reviewed are chosen for their relevance to the subject under investigation, and is aimed to be sufficient, but by no means to be exhaustive.

- 5S
- Value stream mapping (VSM)
- Line balancing
- Takt time
- Just-in-time (JIT)
- Kanban
- Heijunka
- Theory of constraints (TOC)
- Six Sigma

2.1.1 5S

5S is a Lean tool for improving the housekeeping of an operation. The principle: Clean it up, make it visual. Developed in Japan, where the five S’s represent five Japanese words all beginning with an S:

1. Seiri (Organization)
2. Seiton (Neatness)
3. Seiso (Cleaning)
4. Seiketson (Standardization)
5. Shitsuke (Discipline)

In English these have been translated into:

1. **Sort** – Sort through items and keep only what is needed while disposing of what is not.
2. **Straighten** – “A place for everything and everything in its place.”
3. **Shine** – The cleaning process often acts as a form of inspection that exposes abnormal and pre-failure conditions that could hurt quality or cause a machine failure.
4. **Standardise** – Develop systems and procedures to maintain and monitor the first three S’s.
5. **Sustain** – Maintaining a stabilized workplace as an ongoing process of continuous improvement.

The 5S method is a structured sequential programme to improve the workplace organisation and standardisation. 5S improves the safety, efficiency and the orderliness of the process, and establishes a sense of ownership within the team. Quality is improved by better organisation, and productivity is increased due to decreased time spent in searching for the right tool or material at the workstation. Visual control is any communication device used in the work environment that tells at a glance how work should be done and whether it is deviating from the standard. The 5S program focuses on attaining visual order and visual control. 5S is a simple tool and should be considered for the housekeeping and visual control of all types of work area, whether they are in manufacturing or service [15, 16].

Advantages

- The 5S concept is relatively easy to understand.
- 5S is in essence a visual tool. Divergence from the norm and the required action is observable in an instance.
- 5S does not require outside expertise or sophisticated software tools.
- If 5S is executed correctly and everybody in the group is actively involved it will, in turn, create a sense of team identity and a better corporate climate.

Disadvantages

- 5S is very much a group effort. If not everybody is actively involved it is difficult to keep 5S going
- 5S results are difficult to quantify.

2.1.2 Value Stream Mapping

Toyota's Operation Management Consulting Division (OMCD) was created by Taiichi Ohno to lead major TPS projects and teach TPS by doing. He wanted a tool to visually represent the flow of material and information and pull people back from dwelling on individual processes. Ultimately that led to what we now call Value Stream Mapping (VSM) [17].

A value stream is the process flow from the "point of requested need" to "closure of all activity" after the product or service has been provided. In a manufacturing setting, the overall value stream is often defined as from the point an order is received to the point the product is delivered and payment is received from the customer. On the manufacturing floor, however, the focus is typically on the point when raw material arrives to the point when finished product is shipped. This change in focus has allowed Lean practitioners who are utilising the value stream mapping technique to break down departmental and other barriers to focus on systematic causes and solutions. Value stream mapping as a process mapping tool is a way to "see" both the flow and communication within the process.

VSMs are drawn as pictures of the process. Simple, yet logical and powerful representations of the process are used to document both the current state (reality) and the future state (the goal). The Current State Map is the baseline view of the existing process from which all improvements are measured. The Future State Map represents the vision of how the project team sees the value stream at a point in the future after improvements have been made. Value stream mapping is a powerful tool used not only to depict what the current state is, but also to gain acceptance from the employees working within the process under investigation. The objective of creating a VSM is to identify every action required to make a specific product, and to group these actions in three categories [18, 19]:

- Those that create value for the customer.
- Those that do not create value but are currently necessary.
- Those which create no value as perceived by the customer.

Advantages

- VSMs help to make visible the waste present in a process.
- VSMs help to map the whole process rather than only a part of the process
- VSMs help to capture material flow as well as information flow, and shows the linkage between the two.
- VSMs can be drawn up by hand with paper and pencil: sophisticated software is not required.

Disadvantages

- VSM does not work well in a high-variety/low-volume production setting.
- VSM does not work well for parallel processes. It works best for sequential processes.

2.1.3 Line balancing

An important characteristic in industrial manufacturing is the process pattern. In a job shop production system, facilities which perform similar operations are spatially combined in workshops (e.g., all milling machines are combined in a milling shop). In contrast to this job-oriented (functional) organization, the facilities are arranged according to the technological sequence of operations in a flow-line production system. This process-oriented layout is well suited to mass or large-scale series production whereas job shop systems are mainly used in production-to-order and small batch production. Between these two extreme process patterns a number of hybrid systems can be identified which contain properties of both.

For a successful installation of a flow-line production system the following pre-conditions should have been fulfilled:

- Standardized products
- High volume production
- Stable product demands
- Continuous supply of material

Due to its serial layout, a flow-line production system is often organized as an assembly line which consists of a number of work stations arranged along a conveyor of similar material handling equipment. The products are consecutively launched down the conveyor belt and are steadily moved from station to station. At each station, a certain part of the total work, necessary to manufacture the product, is performed. The decision problem of optimally partitioning (balancing) the assembly work among the stations is known as the assembly line balancing problem [20]. The line balancing problem then comprises two aspects:

1. Determining the required number of stations on the line.
2. The assignment of tasks to each station with the objective of maximizing efficiency by minimizing idle time and spreading it evenly across workstations.

2.1.4 Takt time

The word *takt* comes from the German word for rhythm or beat, and is a representation of the rate at which customers require products, and is based on the time we have scheduled to run the products. In mathematical form this translates to:

$$Takt\ time = \frac{Available\ time}{Demand} \tag{1}$$

It is used to determine whether we are producing to meet the customer's requirement according to how we allotted our time (are we ahead or behind?). In other words, do not produce another product until it is confirmed that the previous part was consumed and was good. This basic concept is integrated into other Lean philosophies. One that immediately comes to mind is the concept of Kanban. The Kanban signal is our confirmation to produce and replenish, allowing fast confirmation of consumption and quality. Takt time is like a part-to-part time schedule that needs to be maintained in order to meet the customer requirements. Thus we begin to see the importance of ensuring that the work being done is moving the product closer to completion by the planned time allotted and not simply by keeping the resources busy. Therefore, we should be working only on what is needed now instead of the attitude that it can be shipped (or sold) eventually.

Takt time requires steady customer demand. It does not perform very well when variation in customer orders is high [21].

2.1.5 Just-in-time (JIT)

The just-in-time production concept was implemented by Japanese manufactures to eliminate waste of materials, machines, capital, manpower, and inventory throughout the manufacturing system. The JIT concept has the following goals:

- Receive supplies just in time to be used
- Produce parts just in time to be made into subassemblies
- Produce subassemblies just in time to be assembled into finished products
- Produce and deliver finished products just in time to be sold

In traditional manufacturing, the parts are made in batches, placed in inventory, and used whenever necessary. This approach is known as a push system, meaning that parts are made according to a schedule and are in inventory to be used if and when they are needed. In contrast, JIT is a pull system, meaning that parts are produced to order, and the production is matched with demand for the final assembly of the products.

There are no stockpiles, with an ideal production quantity of one. Moreover, parts are inspected by the worker as they are manufactured and are used within a short period of time. In this way, the worker maintains continuous production control, immediately identifying defective parts, and reducing process variation to produce quality products. Also the extra motions involved in stockpiling parts and then retrieving them from storage are eliminated.

Implementation of the JIT concept requires that all aspects of manufacturing operations be reviewed and monitored, so that all those operations and all the use of resources that do not add value are eliminated. This approach emphasizes pride and dedication in producing high-quality products, the elimination of idle resources, and teamwork among workers, engineers, and management to quickly solve any problems that arise during production or assembly.

The JIT concept of purchasing and delivery is a significant departure from the traditional purchasing of supplies from one or more vendors, whereby deliveries are made (with lead times of weeks or months) in larger quantities and are stored in the inventory. Although a buffer is built into the traditional system, it tends to create large inventory levels and to make controlling the quality of incoming supplies difficult [22].

Advantages

- Low inventory carrying costs
- Fast detection of defects during production or delivery of supplies, and, hence, low scrap loss
- Reduced inspection and rework of parts
- High-quality parts produced at low cost

Disadvantages

- Limited to repetitive manufacturing
- Requires a stable production level (usually about a month long)
- Does not allow very much flexibility in the products produced

- Still requires work-in-progress when used with Kanban
- Vendors need to be located nearby because the system depends on smaller, more frequent deliveries

2.1.6 Kanban

Kanban literally means 'card'. It is usually a printed card in a transparent plastic cover that contains specific information regarding part number and quantity. It is a means of pulling parts and products through the manufacturing or logistics sequence as needed. It is therefore sometimes referred to as the 'pull system'. The variants of the Kanban system utilise other markers such as light, electronic signals, voice command or even hand signals. Kanban is accepted as a way of maximising efficiency by reducing both cost and inventory. The key components of a Kanban are:

- Kanban cards
- Standard containers or bins
- Workstations (usually a machine or a worktable)
- Input and output area

The input and output areas exist side by side for each workstation on the shop floor. The Kanban cards are attached to standard containers. These cards are used to withdraw additional parts from the preceding workstation to replace the ones that are used. This empty container and the card are then sent to the first workstation signalling that more parts are needed for its operation.

A Kanban system may use either a single card or a two cards system. The dual card system works well in a high up-time process for simpler products with well-trained operators. A single card system is more appropriate in a batch process with a higher change over time and has the advantage of being simpler to operate. The single card system is also known as 'Withdrawal Kanban' and the dual system is sometimes called 'Production Kanban'. The system has been modified in many applications, and in some facilities, although it is known as a Kanban system, the card itself does not exist. In some cases the empty position on the input or output areas is sufficient to indicate that the next container is needed.

Advantages

- Kanban enables only small inventory through the plant and pulling only when needed, thus allowing only a small quantity of faulty or delayed material.
- Kanban minimizes the negative aspects of inventory management: including obsolescence, occupied space, working capital, increased material handling and poor quality.
- Kanban uses standardized containers conducive to efficient material handling and lower cost.

- It aims to create work sites that can respond to changes quickly, empowering the operators to exercise their initiatives.
- It facilitates the re-engineering of the process and works in harmony with JIT techniques.

Disadvantages

- It is an inflexible process, as the transfer batch is fixed. Therefore it can cause additional stoppage periods.
- Kanban is inappropriate for high mix, slow mover variants. It struggles with cyclic and seasonal demand.
- It is perceived as a low technology manual process and comes into conflict with the push MRP/ERP systems.
- The application is visible as a solution to a part of the total operation and often not appreciated by employees who are not directly involved with the Kanban system.

The attractiveness of a Kanban system cannot be ignored even in an environment of flexibility and ERP systems. Kanban is best used for fast-moving products containing repetitive manufacturing of discrete units in large volumes which can held steady for a period of time [8, 23].

2.1.1 Heijunka

In order to establish a Lean system, it is essential to eliminate, not only waste (non-value added activities), but also unevenness in workflow and the practice of overburdening people and machines. Stabilising and creating "evenness" – a balanced flow of work – is the concept of Heijunka.

Unevenness results from an irregular production schedule or fluctuating production volumes due to internal problems, like downtime or missing parts or defects. Non-value added activities will be a result of an unevenness in workflow. Unevenness in production levels means it will be necessary to have on hand equipment, material, and people for the highest level of production, even if the average requirements are much lower than that.

To achieve the Lean benefits of continuous flow, one needs to level out the workload. Eliminating non-value added activities is only one third of achieving flow. Eliminating the practice of overburdening people and machines, and smoothing out unevenness are equally important. Heijunka focuses on levelling the product volume and mix, and, most importantly, levelling out the demand on people, equipment, and suppliers. Standardised work is easier, cheaper, and faster to manage. Without levelling, wastes naturally increase as people and equipment are driven to work beyond their capability ,and then stop and wait - much like the proverbial hare [15].

2.1.2 Theory of constraints (TOC)

As an operations improvement tool Theory of Constraints (TOC) concentrates its efforts only on the operation that is constraining a critical process, or on the weakest component that is limiting the performance of the system as a whole. If these elements are effectively managed, then it follows that better overall performance of the system relative to its goal is more likely to be achieved. TOC uses the following five-step approach:

1. Identify the systems constraints
2. Decide how to exploit the system constraints
3. Subordinate everything else to that decision
4. Alleviate the system constraints
5. If, in the previous step, the constraints have been broken, go back to step one

Underlying the TOC approach is the notion of synchronous manufacturing, which refers to the entire production process working in harmony to achieve the goal of the firm. When manufacturing is truly synchronised, its emphasis is on total system performance, not on localised measures such as labour or machine utilisation [24, 25].

2.1.3 Six Sigma

Six Sigma is a philosophy of doing business with a focus on eliminating defects through fundamental process knowledge. Six Sigma methods integrate principles of business, statistics, and engineering to achieve tangible results. Six Sigma tools are used to improve the processes and products of a company. They are applicable across every discipline, including production, sales, marketing, design, administration, and service.

Whereas Lean tools focus on the reduction of waste, Six Sigma's focus is on defect reduction. More specifically: Six Sigma pertains to the attainment of desirable situations in which the fraction of unacceptable products produced by a system is less than 3.4 per million opportunities.

A disadvantage of Six Sigma is that, in order to implement it, advanced scientific and statistical knowledge is required. This undermines the empowerment of workers involved in production, thus opposing the Lean philosophy where worker empowerment is the main pillar on which quality is build [26].

The concept of flow is closely linked to Lean manufacturing. The proximity of a subsequent activity in a process, or how departments are laid out relative to each other has an effect on the flow of a product. In other words: the waste present in a process is unequivocally linked to the way a process or plant is laid out. An integral part of reducing waste in a process is to find the optimum plant lay-out.

2.2 Plant Layout

When determining the requirements of a plant the three important aspects to consider are flow, space, and activity relationships. Flow variables are lot sizes, unit load sizes, material handling equipment and strategies, layout arrangement, and building configuration. Space is a function of lot sizes, storage system, production equipment type and size, layout arrangement, building configuration, housekeeping and organization policies, material handling equipment, and office, cafeteria, and restroom design. Activity relationships are defined by material or personnel flow, environmental considerations, organizational structure, continuous improvement methodology (teamwork activities), control issues, and process requirements [27]. On the other hand, having insight into what influences the *performance* of the plant can help during design, operation, and control of the plant. There are two types of models that can be used to assist in identifying the flow, space, and activity relationship variables that are key to the performance of a plant; analytical and simulation models [28].

2.2.1 Analytical models

Analytical models such as ALDEP, CORELAP, and others have been applied to the problem of selecting the most effective arrangement of physical facilities to allow greatest efficiency in the combination of resources in order to produce a product or service [29, 30]. To analytically evaluate the performance of a plant, a probability law for all the variables governing a change in the production process will have to be constructed [31]. It is impossible though, for an analytical model to capture all the production process variables. Too much detail makes the model impossible of solution; too little makes the model unrealistic [28].

2.2.2 Simulation models

The advent of fast and inexpensive computational power has opened the door to an alternative approach: simulation models. Simulation models make use of random number generation to generate the values of random variable from arbitrary distributions. The random variables can then be used to generate the behavior of a stochastic model over time and obtain estimators for desired quantities of interest [31]. Simulation models can be categorized in two groups; representational graphic models and iconic graphic models. The output of representational graphic models are typically bar charts, line plots, pie charts, or other forms of data representation. In contrast, an iconic graphic model *displays* the system under investigation. The model is dynamic, allowing the user to watch and analyze the system as it evolves over time [32].

As mentioned above, besides flow and space, one also needs to consider the activity relationships aspect when determining the requirements for a plant. In case of a food processing plant this is particular important: consumer health and safety depend on it. It is unacceptable to produce contaminated food.

The modelling approach has been applied for design and development of food processing equipment in order to eliminate contamination risk. The food processing industry maintains the highest number of product variations, some of which are short lived or seasonal, a factor with which the processing equipment has to cope [33].

2.3 Allergen Control

In the specific case of an FMCG food processing plant, there is a further constraint: food hygiene. This requires greater attention to personal hygiene, protective apparel (gloves, facemasks, hear nets), and intermediate packaging/storage. Work in progress product cannot be left in the open for any extended period of time. This all adds cost in terms of consumables, and hence another variable to optimise. There is also a lot of cleaning required of machines between products. This adds setup time. Furthermore, there is the issue of allergen control. This is increasingly becoming important, as it is an area of unease for consumers, sometimes even life-threatening. Implementing allergen control on top of other production optimisation methods is a difficult task.

Food allergy is the term used to describe an adverse immune response to food [34]. The adverse immune response may take the form of, for example, a rash, vomiting, asthma, or, in severe cases, a fatal anaphylactic shock [35, 36]. The most common allergenic foods are: milk, peanuts, tree nuts, shellfish, fish, soy, wheat, and eggs [37]. It is the proteins in these otherwise safe foods that are triggering the allergic reaction, and it is these proteins that are known as allergens [38]. Literature suggests a 3% - 6% prevalence of food allergy [39]. This number has to be approached with caution though: prevalence varies with age, geographical location, and possibly race/ethnicity [35, 40]. The effective management of hazards posed by allergens can only be achieved when designed into food manufacturing processes in particular, and overall food safety management systems in general [41]. Much work has been done to reduce the likelihood of consumers being involuntarily exposed to allergens. This includes work relating to each of the five stages of food chain operations (Figure 2), as well as work relating to the overarching management structure to manage these operations.

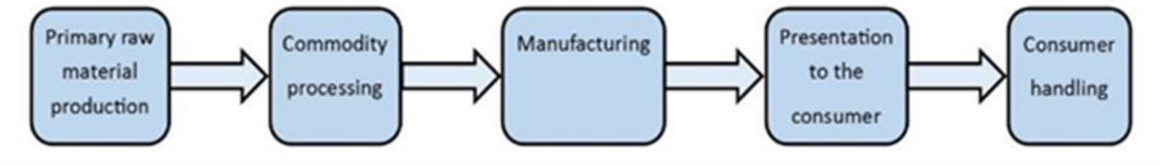


Figure 2. A generic five stage food supply chain

2.3.1 Primary raw material production

A first priority in the management of food allergy is the identification of food allergens. Protocols for protein extraction from foods and for allergen purification have been designed in order to be able to study the biological and immunological characteristics of allergens [42]. Having identified the food allergens it has been proved possible to modify raw materials. That is, genetic engineering has been applied to rice, soybean, apple, tomato, and peanut to eliminate or substantially reduce allergens from these crops [43].

2.3.2 Commodity processing

The allergenicity of commodities such as milk, peanuts, tree nuts, fish, soy, and eggs might be altered by processing procedures such as, peeling, cooking, or roasting. The allergenic activity may be unchanged, decreased or increased by such food processing procedures [44, 45].

2.3.3 Presentation to the consumer

Manufacturers are required to list the ingredients used in their products in accordance with the law [46, 47]. That includes allergens. Not meeting requirements can lead to food recalls and, possibly, hospitalisation of the consumer [48, 49]. A common way for a manufacturer to inform the consumer about possible unintentional allergen cross contact on a production line, and hence abiding the law, is through precautionary labels such as “May contain” and “May be present” [50]. The use of precautionary labels is not regulated and hence no integrated approach amongst manufactures exists. In order to provide the allergic consumer with clear and consistent information, ongoing efforts are made to avoid the indiscriminate use of precautionary labelling [51-53].Also, research has been conducted on how to improve the effectiveness of communicating to the consumer via food safety messages [54]. It has been put forward that, in order to promote an integrated approach amongst manufactures, it is necessary to reduce the diversity and complexity of the legislation involved with food laws and labelling rules [55].

2.3.4 Consumer handling

Consumers often behave in a way that seems irrational, illogical or inconsistent to scientists and policy makers involved in risk analysis [56]. This means that, although the manufacturer may provide all the required information on the product, the required consumer-response may not necessarily be achieved [57]. Moreover, it is well documented that a localised incident can have global economic consequences of catastrophic proportions [58].

2.3.5 Management structures

With global food markets becoming increasingly more common place [59], we also see scaled up food supply chains and diversification of food on the market. As a result manufactures are required to adapt and improve the food safety management systems on a continuous basis as well [60]. Hazard Analysis Critical Control Point (HACCP) is the internationally accepted standard in the food industry to assure food safety [61-66].

2.3.6 Manufacturing

The two strategies used in manufacturing to reduce the likelihood of allergen cross contact on production lines are separation and scheduling [37]. The separation strategy requires the allergens to be separated spatially (Figure 3a), whereas the scheduling strategy requires the allergens to be separated in time (Figure 3b).

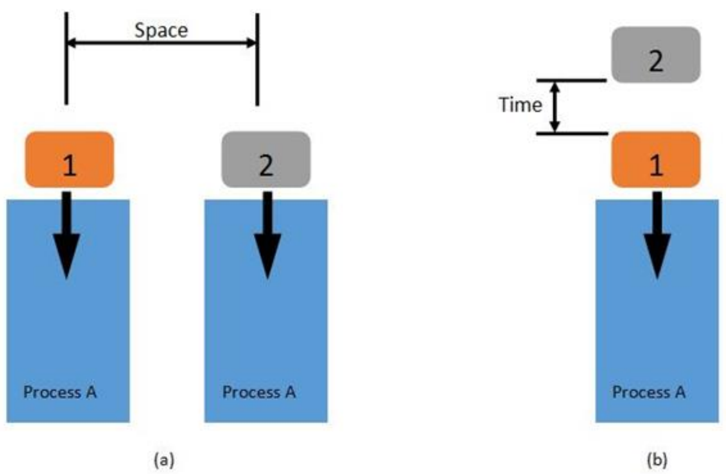


Figure 3. Allergen control strategies: (a) Spatial separation, (b) Temporal separation

The use of the separation strategy may mean assigning a dedicated plant, a dedicated line, or dedicated equipment and tools to a specific product group. The ability to run full scale separation might be hampered by the lack of resources such as floor space or funding. Where spatial separation via dedication is not possible, temporally scheduling becomes the norm. But also scheduling is not always possible. The ability to use scheduling as a means for allergen control might be hampered by restrictions on supply, or demands on delivery. When scheduling is hampered, cleaning becomes paramount. An important factor in the control of allergen cross contact is the cleanability of process equipment. Attempts have been made to quantify the in-line cleanability of equipment using flow modelling [67], residual contaminants [68], and in-line testing [69]. Furthermore, research has been conducted on the formation of surface deposit on food processing equipment [70], and the nature of airborne particles generated by cleaning [71]. In particular, a recommended cleaning regime has been proposed to achieve efficient cleaning to ensure allergen control [72]. Although separate constituents that make up a food manufacturing process have been researched, a methodology to optimize plant-wide production control for reduction of allergen cross contact is currently lacking in literature.

2.4 Modeling for Allergen Control

The focus of this work is on reducing the risk of allergen cross contamination during manufacturing. Simulation models have been used to analyse possible benefits of lean manufacturing and VSM [73]. VSM was used as the main tool to identify improvement opportunities, followed by the creation of a simulation model to develop a 'before' and 'after' scenario. Allowing the practitioner to communicate to management the proposed changes to the plant prior to implementation.

Mathematical modelling has been applied to evaluate scheduling strategies. Using a scheduling methodology that takes into consideration food groups that classify products based on the allergens they contain allows for more efficient production while reducing cross contact risk [74, 75]. Also, mathematical modelling has been applied to calculate the cost associated with a specific quality level to HACCP-based system implementation [76].

Chapter 3
Methodology

3.1 Purpose

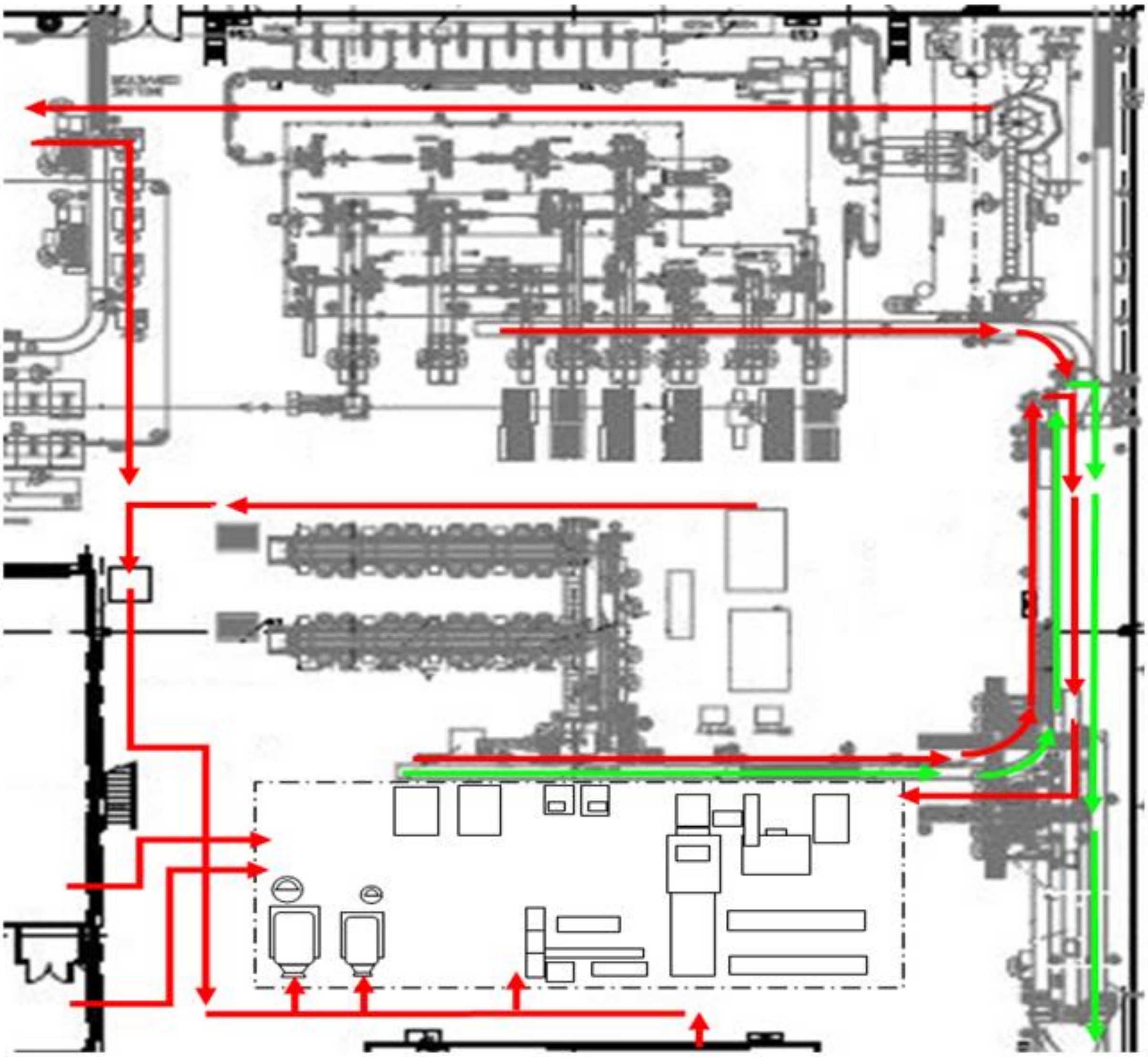
The purpose of this project was to provide an integrated solution to the problem of optimising plant production flow while also optimising allergen control. That is, to improve process flows, improve equipment utilisation, reduce work-in-process (WIP) inventory, and reduce unnecessary movement of stock while also optimising allergen control in the area under investigation.

3.2 Scope

The VA sub-plant processes are affecting, and are affected by, processes both in and outside the overall plant (Figure 4). Ideally, all the processes sending product into the VA area, as well as those receiving product from the VA area, should be analysed. This however is beyond the scope of this project. A system boundary as shown in Figure 4 has been defined. As a result of this system boundary the variables associated with product flowing into VA will be considered a given. These variables include:

- Volume / Quantity
- Type of container
- Time of arrival
- Place of arrival

Furthermore, the system boundary also excludes limitations on capacity on processes downstream.



: Product coming into the VA area.

: Product leaving the VA area.

: System boundary.

Figure 4. System boundary for area under investigation

3.3 Method

A systems engineering method was applied to the problem. System engineering is understood to be the interdisciplinary approach and means to enable the realisation of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem[77]. In this context a system is regarded as a construct or collection of elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce system-level results. The results include system level qualities, properties, characteristics, functions, behaviour and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are connected. The specific systems engineering tools used were:

- 5S
- Line balancing
- Value stream mapping (VSM)
- Plant simulation

Important features of the problem under investigation were the need to model transient discrete (batch) flow of diverse products, variable input and output demand, accumulation of transitional inventory, spatial layout, quality demands, machine failure, and resource allocation. 5S, line balancing, and VSM were used as a tool to analyse the individual processes comprising the plant prior to plant-wide analysis. The specific simulation tool used for plant-wide analysis was Tecnomatix. Tecnomatix is a product that is part of the Product Lifecycle Management (PLM) software package developed by Siemens. Tecnomatix is a portfolio of digital manufacturing solutions able to link manufacturing disciplines together with product engineering – from process layout and design, process simulation and validation, to manufacturing execution.

3.4 Approach

The problem was approached in the following way (Figure 5). The first stage of the project was the embedment of the researcher in the area under investigation. The second stage was the analysis of the individual processes that, combined, make up the VA plant. The tools used in stage 2 were 5S, line balancing, and VSM. Stage three was a plant-wide systems analysis using Tecnomatix, and stage four was the implementation of the proposed interventions as deduced from the analysis in stage two and stage three. Stage five was the documentation of the efficacy of implemented changes.

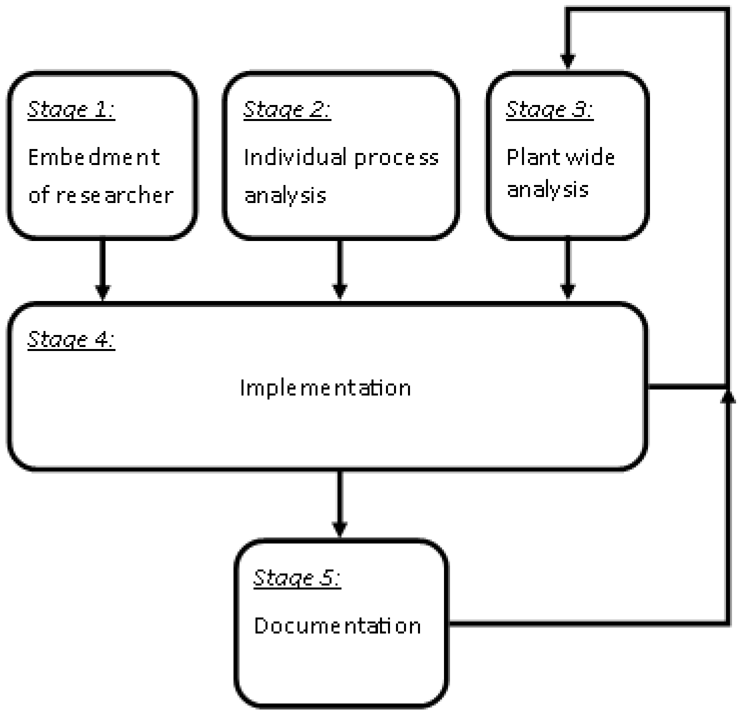


Figure 5. Approach flowchart. Note, stage 1, stage 2, and stage 3 are *not* occurring sequential, but rather concurrently and synchronously.

3.4.1 Embedment of the researcher

Stage one was a stage of familiarisation for both the researcher and VA plant operators. The researcher worked 180 hours over a period of 2 months alongside operators to engage with them, and become familiar with work processes, procedures, and equipment and tools. The researcher partook fully in the production process, meaning that, besides being allocated to a variety of different work stations on different process lines, he also took on cleaning duties and worked overtime when required. The rationale behind emerging the researcher fully in all the different attributes of VA-plant production, was firstly, to let him experience first-hand the work processes and procedures used in the plant: it might be difficult for operators to express and communicate verbally the requirements for running the machines and using the tools effectively. Having insight into the extent of tacit knowledge being used to run the plant might be of an invaluable importance to the researcher. Secondly, the embedment of the researcher was used to gain trust and secure buy-in from staff. Before any major change can be implemented staff will have to feel assured that the researcher's main concern is to address the shortcomings of the *system*, as opposed to exposing the shortcomings in individual staff members. It is the shortcomings imposed on staff by the system that debar staff from producing more efficiently. For this project, having the researcher working alongside VA-staff and having him recognise, experience, and then cope with the shortcomings of the system himself, was a deliberate action meant to instil in staff a trust in the researcher's sincerity to help them to overcome the shortcomings of the system.

3.4.2 Individual process analysis

The second stage of the project was the analysis of the individual processes within the VA plant. To reduce the likelihood of 'carrying over' any wastes into the final plant layout it was deemed important to evaluate each main process separately before analysing the plant as a whole.

Changes to plant layout can be perceived very negatively by operators who are used to certain arrangements. To avoid unnecessary resistance, the interventions were made as follow. The main premise was to build on the trust gained in stage 1, and expand this trust by introducing and implementing adjustments and reversible changes. A reversible change might be, for instance, the relocating of a table. By not implementing major changes immediately, but starting off with reversible changes, staff was left to feel 'in control' while letting go of familiar ways of doing things.

The adjustments and changes were instigated by the implementation of the 5S, line balancing, and VSM. 5S is a Lean tool for improving the housekeeping of an operation. The principle: Clean it up, make it visual. Developed in Japan, where the five S's represent five Japanese words all beginning with an S, that is, Sort, Straighten, Shine, Standardise, and Sustain. In the context of 5S these mean:

- Sort: Eliminate parts and tools not required in the process
- Straighten: Eliminate all tasks that do not add value to the product
- Shine: Keep it clean and organised
- Standardise: Ensure uniform procedures and set-ups throughout the process
- Sustain: Ensure disciplined adherence to rules and procedures

Line balancing is a tool used to assign an indivisible activity to a single station, while making sure the precedence constraints are observed, and the station times do not exceed the cycle time.

VSMs are commonly used to reduce the lead time. The lead time is not an issue in this case as customer demands are satisfied. Products are delivered daily, on time, and at the required volumes. VSMs are here used to reduce non-value added time, reduce WIP, and balance the production lines.

After having determined the main process flows within VA the researcher used VSMs to analyse these processes in order to decide what changes to propose next. The VSMs were used as a starting point for discussion with VA team leaders as well as a means to introduce to VA staff the upcoming changes. The visual nature of the VSMs proved invaluable tool.

The following steps were implemented to construct the VSMs:

1. Identify a target process

2. Construct a current state VSM by identifying the steps making up the target process and collecting data on these steps.

3. Construct a future state VSM by eliminating, where possible, from the currents state VSM the steps that constitute waste.

In effect, stage two was a confirmation to staff of the embarking of staff and researcher on a progressive journey of change guided by the researcher for the benefit of staff. In light of the Lean assertion ‘buy-in through ownership’, the researcher left it up to staff to organise the proposed changes *in detail*, and, as such, the Sustain phase of the 5S methodology was not strictly imposed early on in the change process.

A novel feature of the methodology was to start with the functional layout (process tree), map that onto the spatial layout (equipment location on the floor-plan), to application of VSM in the time domain. Then the problem was optimised in the time domain by removing non-value added time from the VSM, to create a future state. That future state was then mapped back onto the spatial layout, .i.e. the implications were determined for of the positions of plant.

3.4.3 Plant-wide analysis

The third stage of the project was the plant-wide analysis stage. In stage two of the project, staff saw changes being implemented successfully and realised embracing change might lead to beneficial outcomes. To keep the momentum going, and consolidate staff buy-in, the researches next looked at introducing more intrusive changes. Plant simulation models were used to analyse allergen control strategies.

The following steps were implemented to construct the plant simulation models:

1. Formulation of the problem
2. Testing for simulation-worthiness
3. Formulation of simulation objectives
4. Data collection and data analysis
5. Modelling
6. Execution of simulation runs
7. Result analysis and result interpretation
8. Documentation

3.4.4 Implementation

Stage four was the introduction and application of the required interventions as deduced from the analysis of stage two and three. While stages two, three and four are presented in this paper as occurring in sequence, in practise they were concurrent and progressive.

3.4.5 Documentation

The fifth and final stage of the project was measuring and documenting the efficacy of the implemented changes. The way in which the efficacy of each change was measured depended on the expected effect of the change. For example, a change introduced to reduce the clutter on the work floor could not be readily measured in terms of dollars or time. Clutter was ubiquitous in VA, and since it was not being specific to one particular process, it would have required measuring the change in overall plant efficiency to determine the efficacy of the intervention. It would be fatuous however, to ascribe a change in overall plant efficiency to a reduction of clutter on the floor while having implemented a change to a process to necessitate the reduction of clutter. Also, since clutter not being specific to a process, and thus with efficacy having to be measured plant wide, the conditions pre and post interventions have to be comparable: a feat impossible to achieve with ever changing production volumes and product mix.

Chapter 4
Stage 2 Results

4.1 Inceptive analysis

As part of company protocol the researcher received the same health and safety induction as any new staff member would receive. Likewise, like any new staff member, he first was given the more easy jobs to do, such as cleaning and taking out the rubbish, before moving on to more demanding jobs requiring higher levels of skill and dexterity. On commencement of the project the researcher found the layout of the plant to be as shown in Figure 6. On first impression it appeared chaotic, and work was done in an ad hoc fashion; the proverbial fire fighting. Staff were each fighting their own battles rather than working as a team. This was mainly due to fragmentation of the processes. Each staff member was responsible for, and took ownership of, a part of a fragmented process. They performed their assigned task to the best of their ability, but without taking into consideration the tasks preceding, nor the tasks following on, from their own task. This led to a significant amount of clutter on the work floor. The clutter — consumables, raw material, WIP, and finished product — was habitually being moved 'out of the way' throughout the workday.

When executing certain tasks staff would use a specialised table. The tables were positioned on their assigned place on the floor, and used only for one particular task. Once the task was completed the table was left in position, unused, further reducing the available floor space while adding to the clutter. Although Figure 6 might imply clearly defined workspaces and discernable product flows, in practise this was not the case. To give an indication of the complexity of the plant during production Figure 7 has been included.

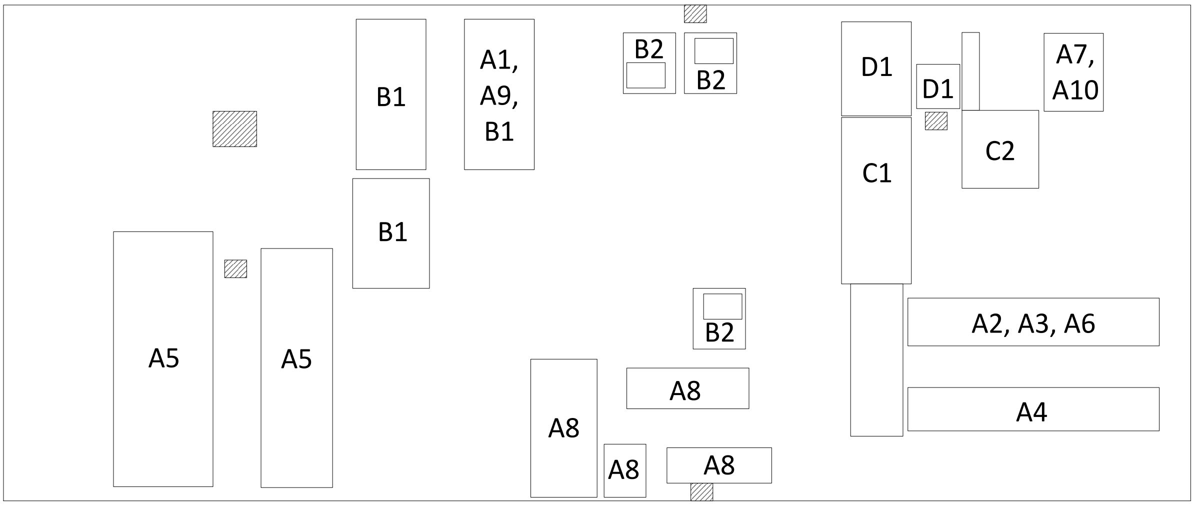


Figure 6. Original layout of the VA Plant.

Figure 7. VA plant during production. On first glance, no descernible process lines can be observed.

4.1.1 Product-quantity (PQ) analysis

In order to be able to determine the processes used in the VA plant, a list of products produced in the plant was compiled. The products were then arranged by product group (Table 1). These product groups and there associated production costs were subjected to an ABC analysis to determine the main contributors to production cost (Figure 8, Table 2). On inspection it was found that 10 distinct process lines were used to produce all the product groups (Figure 9). Out of these 10 process lines several were produced on a simple process line. A simple process line is defined as being a process line consisting of no more than 4 activities. The simple process lines were considered not complex enough to be analysed as part of this project. Other processes, although sufficiently complex, had volumes associated with them that did not warrant an in-depth analysis. What remained were 6 product groups that were considered both complex enough, as well as having volumes associated with them to warrant an in-depth analysis (Table 1). The 6 selected product groups accounted for 38% of total production cost (Figure 10). The 6 product groups were identified as being produced on 5 distinctly different process lines:

1) Product group 1 on process line A8/B2/C2/D1
2) Product group 4 on process line A6/C2/D1
3) Product group 6, and 10 on process line A4/C1/D1
4) Product group 14 on process line A9/B2/C2/D1
5) Product group 17 on process line A4/D1.

The 17 product groups with an associated volume of less than 1% of total volume accounted for 5% of total production cost. The 12 product groups that were simple processes with an associated volume of more than 1% of total volume accounted for 57% of total production cost: a significant percentage. Subsequently, the 6 product groups produced on the 5 major process lines were analysed first, then using the resulting modified processes as the main contributors to the initial design of the final layout of the plant - fine tuning the layout by adding the remaining 12 simple processes to obtain the definitive plant layout. The final layout was designed having taken into consideration the processes accounting for approximately 70 % of total production volume, and 95 % of the total production cost.

Table 1. VA Plant product groups sorted by production cost (censored for confidenciality reasons)

Product Group Name	Product Group Number	Weight [kg]	Production Cost	Simple Process Line	Less than 1% of total kg	Selected Process
[illegible]	Group 1	107,899	923,747			X
[illegible]	Group 2	100,492	805,145	X		
[illegible]	Group 3	268,643	778,555	X		
[illegible]	Group 4	79,827	582,282			X
[illegible]	Group 5	70,110	434,530	X		
[illegible]	Group 6	31,404	367,367			X
[illegible]	Group 7	54,400	310,685	X		
[illegible]	Group 8	103,287	286,457	X		
[illegible]	Group 9	34,453	191,625	X		
[illegible]	Group 10	22,305	182,575			X
[illegible]	Group 11	49,190	151,908	X		
[illegible]	Group 12	44,815	122,048	X		
[illegible]	Group 13	35,334	116,882	X		
[illegible]	Group 14	11,795	107,779			X
[illegible]	Group 15	12,719	99,372	X		
[illegible]	Group 16	13,374	94,404	X		
[illegible]	Group 17	33,190	88,033			X
[illegible]	Group 18	8,046	74,616	X	X	
[illegible]	Group 19	8,455	50,311	X	X	
[illegible]	Group 20	5,703	43,613	X	X	
[illegible]	Group 21	12,533	40,989	X		
[illegible]	Group 22	3,245	34,404	X	X	
[illegible]	Group 23	7,426	30,581	X	X	
[illegible]	Group 24	4,252	26,072		X	
[illegible]	Group 25	1,243	13,525	X	X	
[illegible]	Group 26	729	4,810		X	
[illegible]	Group 27	843	3,854	X	X	
[illegible]	Group 28	387	3,552		X	
[illegible]	Group 29	839	3,448		X	
[illegible]	Group 30	324	2,229		X	
[illegible]	Group 31	274	1,961		X	
[illegible]	Group 32	205	1,413		X	
[illegible]	Group 33	115	1,367	X	X	
[illegible]	Group 34	127	298	X	X	
[illegible]	Group 35	6	67	X	X	
	Total	1,127,988	5,980,504			

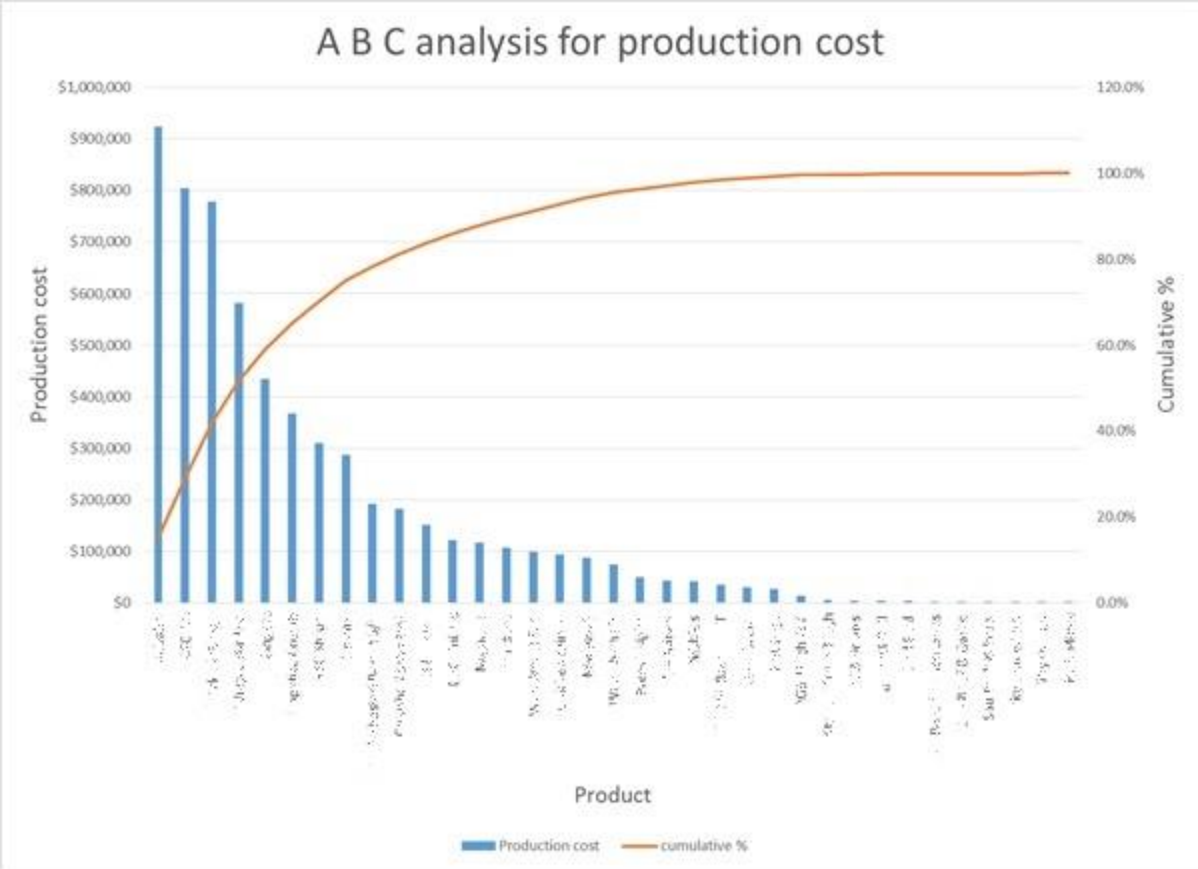


Figure 8. ABC analysis for production cost (Sensored for confidentiality reasons).

Table 2. 20/30/50 analysis for production cost (Sensored for confidentiality reasons).

Product group	Production cost	%	cumulative %	
[illegible]	$923,747	15.45%	15.4%	20%
[illegible]	$805,145	13.46%	28.9%	30%
[illegible]	$778,555	13.02%	41.9%	30%
[illegible]	$582,282	9.74%	51.7%	30%
[illegible]	$434,530	7.27%	58.9%	50%
[illegible]	$367,367	6.14%	65.1%	50%
[illegible]	$310,685	5.19%	70.3%	50%
[illegible]	$286,457	4.79%	75.1%	50%
[illegible]	$191,625	3.20%	78.3%	50%
[illegible]	$182,575	3.05%	81.3%	50%
[illegible]	$151,908	2.54%	83.9%	50%
[illegible]	$122,048	2.04%	85.9%	50%
[illegible]	$116,882	1.95%	87.8%	50%
[illegible]	$107,779	1.80%	89.7%	50%
[illegible]	$99,372	1.66%	91.3%	50%
[illegible]	$94,404	1.58%	92.9%	50%
[illegible]	$88,033	1.47%	94.4%	50%
[illegible]	$74,616	1.25%	95.6%	50%
[illegible]	$50,311	0.84%	96.5%	50%
[illegible]	$43,613	0.73%	97.2%	50%
[illegible]	$40,989	0.69%	97.9%	50%
[illegible]	$34,404	0.58%	98.4%	50%
[illegible]	$30,581	0.51%	99.0%	50%
[illegible]	$26,072	0.44%	99.4%	50%
[illegible]	$13,525	0.23%	99.6%	50%
[illegible]	$4,810	0.08%	99.7%	50%
[illegible]	$3,854	0.06%	99.8%	50%
[illegible]	$3,552	0.06%	99.8%	50%
[illegible]	$3,448	0.06%	99.9%	50%
[illegible]	$2,229	0.04%	99.9%	50%
[illegible]	$1,961	0.03%	99.9%	50%
[illegible]	$1,413	0.02%	100.0%	50%
[illegible]	$1,367	0.02%	100.0%	50%
[illegible]	$298	0.00%	100.0%	50%
[illegible]	$67	0.00%	100.0%	50%
Total	$5,980,504			

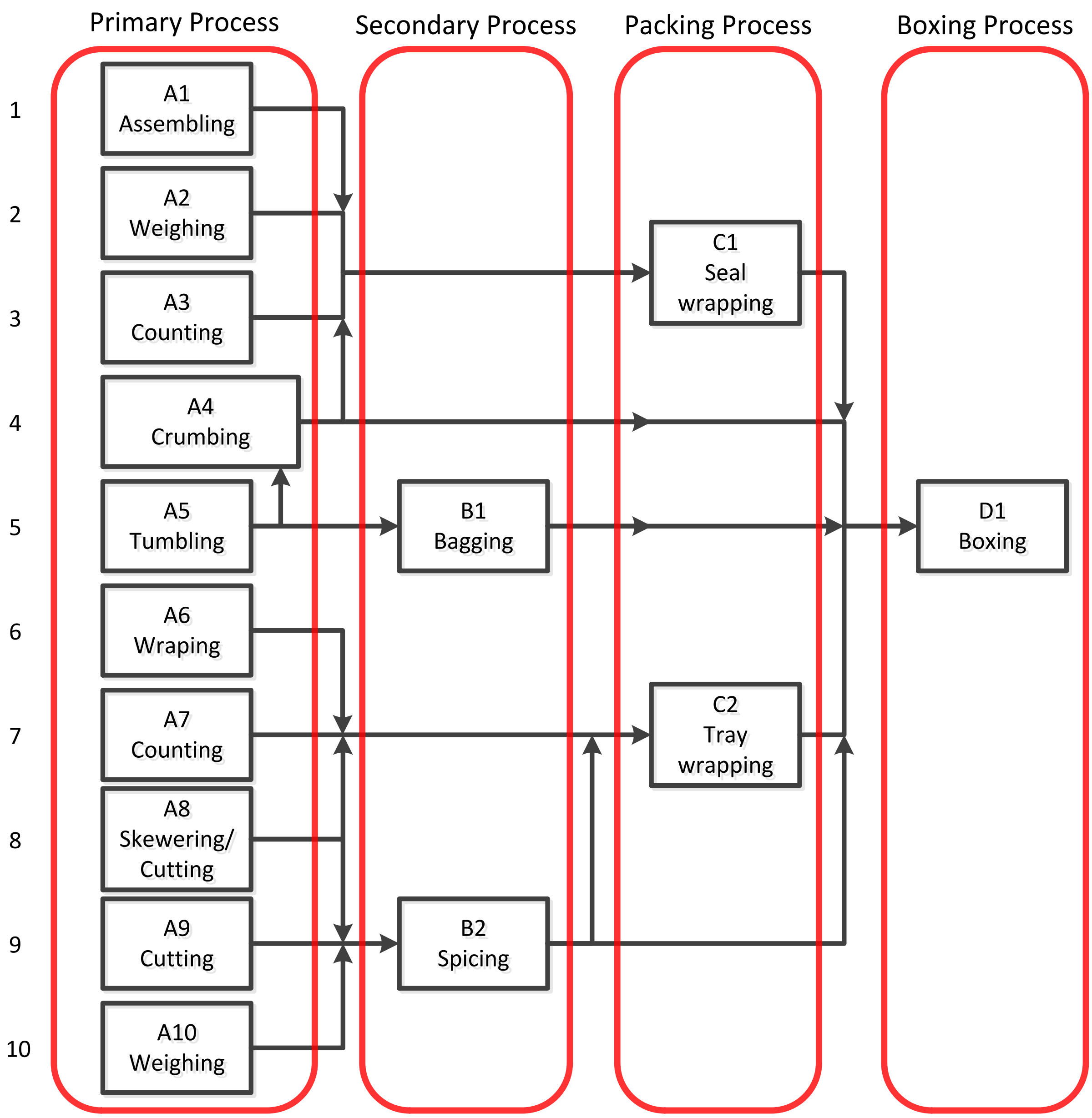


Figure 9. Process flow in the VA plant.

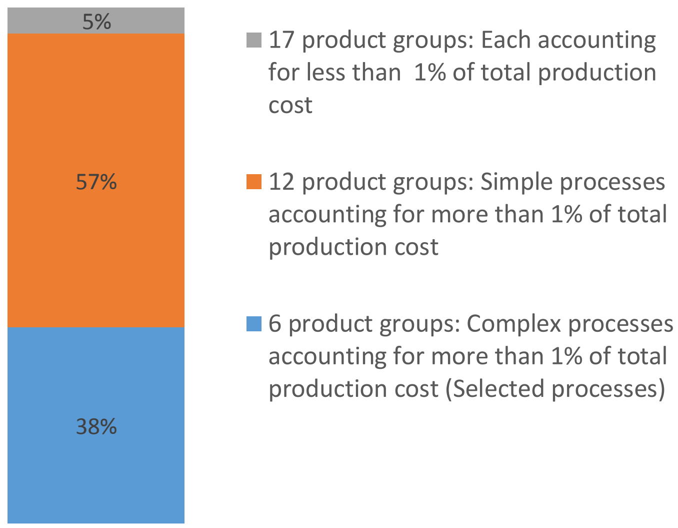


Figure 10. Percentage of total production cost per product group.

4.2 5S

4.2.1 Process A8

While working on process A8 (Figure 11) the researcher noticed the position of the machines changed significantly from day to day. The machines and the tables used in the process were not fixed in position but had to be re-aligned daily before starting production. Inquiring with staff why the machines and equipment were moving revealed that staff were aware of the problem, found it annoying, but had no idea why it happened or what to do about it. On closer inspection the researcher found that machinery was not properly installed. Only three out of four machine levelling feet of each machine were touching the floor, resulting in the linear motion of the machine's mechanisms to translate into an overall rocking motion, causing the machines to 'walk' from their positions.

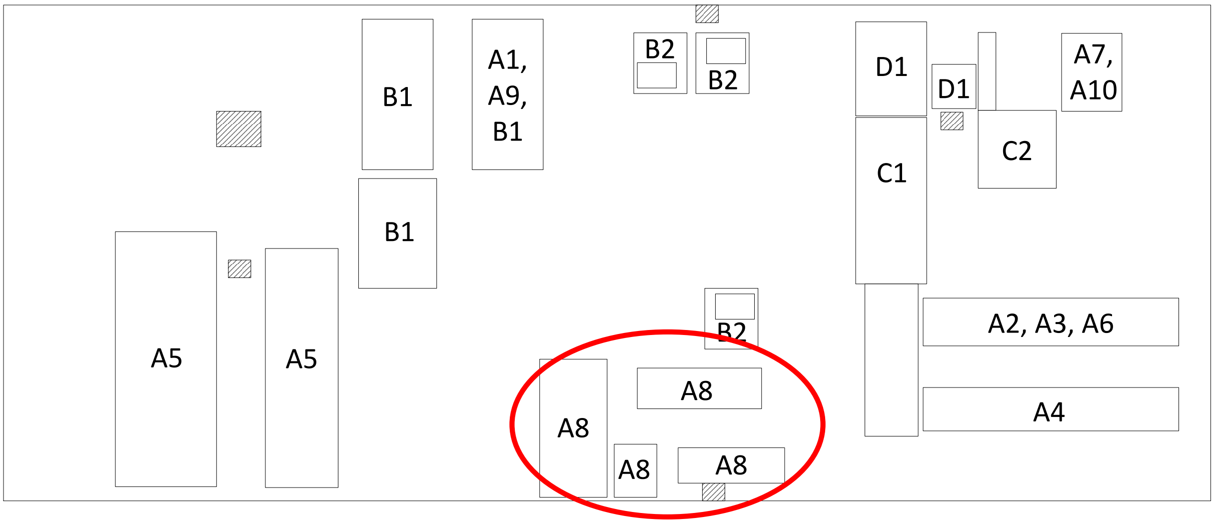


Figure 11. Process A8 adjustment.

The problem was remedied by assuring the weight of each machine was properly distributed equally over all its four legs. With machines firmly in place staff did not have to push and pull the machines to re-align them.

In light of the 5S methodology process A8 had not yet been Sorted: the researcher suspected that not all tables and tools used were a necessary part of the process. But instead of introducing major changes right from the start the researcher choose to start with introducing reversible changes. So, the required step was to Straighten the process. In terms of 5S this means the elimination of any activity that does not add value to the product. Be aware: it does not mean to physically line things up, although in affect that is what was done in this particular case. The re-aligning of machinery and tables before commencing production was a wasteful activity that was not adding value to the product. As such, this activity had to be eliminated.

This adjustment to machinery was the first change introduced by the researcher. Although the change might have been small, it carried a profound meaning. Since the change was instigated by the researcher experiencing the problem himself, recognising it as being a problem, engaging staff and communicating with staff about it, and finally, resolving the issue, this small adjustment was signalling the embarking on a progressive journey of change for both staff and researcher based on mutual respect and understanding.

4.2.2 Process B1

While working on process B1 the researcher observed an ever present struggle amongst staff for floor space. The available floor space was shared by several different processes simultaneously – process A1 and A9, and process B2. The available floor space was used to store raw materials and consumables, execute the processes, store final product, as well as move transitional WIP. The work floor appeared cluttered and work processes chaotic. As a result of the restricted availability of floor space, staff had difficulties maintaining required standards of cleanliness in general and allergen control in particular. Staff argued that the problem had become worse over time. Asking them what might have caused the problem to escalate they replied that it was not the increase in volume, but the diversification of product that had led to the clutter and chaos on the work floor. Although the project boundary was defined as shown in Figure 4, the affective area in use was much less due to the encroachment of neighbouring departments upon the area.

The researcher proposed to the VA plant team leader to claim back the floor space assigned to the plant that had been encroached upon by neighbouring departments, and use that space to execute process B1. The researcher mediated between the VA plant team leader and the team leaders of the neighbouring departments. The floor space was cleared, and process B1 was relocated (Figure 12).

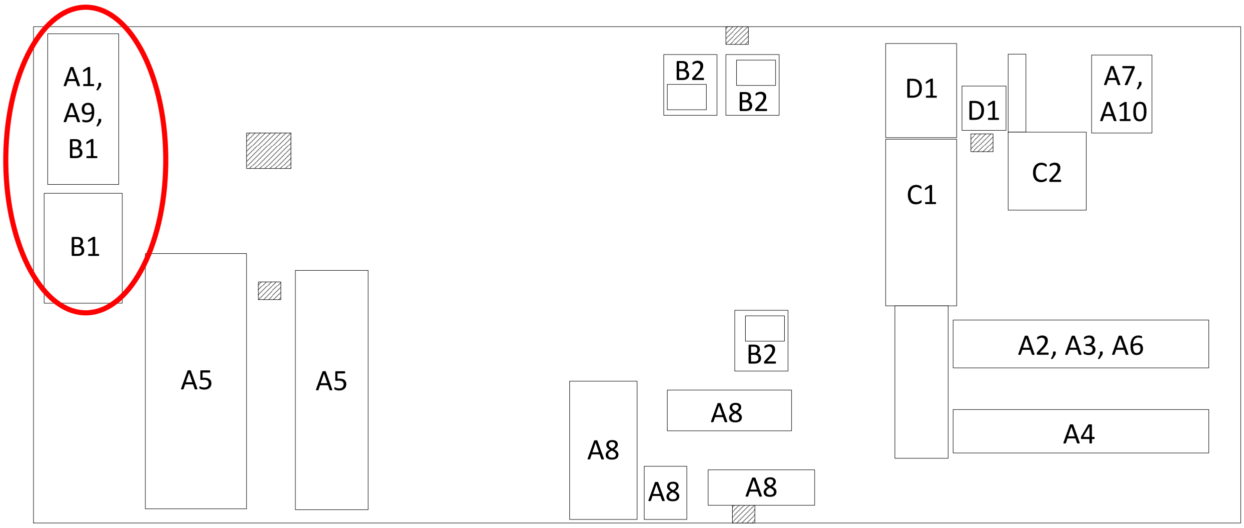


Figure 12. Relocation of process B1.

In light of the 5S methodology the process B1 had already been Sorted and Straightened: it being a simple process, there were no obsolete tools or parts being used, and all steps of the process were adding value to the product. The required next steps were Shine and Standardise, that is, keeping it clean and organised and ensuring uniform procedures and set-ups throughout the process. Since the process B1 was now assigned to its own space on the floor, and was not being interfered with and obstructed by other processes, staff was able to place their consumables, such as, bags, bins, and zip ties, in and orderly and organised fashion, and was able to keep it that way throughout the day. Likewise, having the process B1 on one side of the floor created space in the centre of the floor where the processes could now be organised in more detail. Staff was able to organise the processes they were working on by assigning designated areas to raw materials, consumables, and final product, while creating space to move transitional WIP. A direct result of a more organised process B1, was the becoming obsolete of the second B1 table, freeing up even more space on the floor.

The relocation of process B1, the second intervention introduced by the researcher, was one which had a more fundamental impact. Whereas for the first intervention — adjusting the feet on process A8 machines — the overall plant layout had stayed the same, the second change had a visual effect on the layout: things had moved and were different from what they were before. A consolation was offered by the researcher to apprehensive staff members by pointing out that the change was reversible. The offered solace persuaded staff to 'have a go' at proposed change.

It should be noted that 7 out of 12 product groups, namely product group 2, 3, 5, 7, 11, 12, and 21 (Table 1), are considered a simple process and are produced on process line A5/B1/D1 (Figure 13). This will become important when fine tuning the final layout by adding the remaining 12 simple processes to obtain the definitive plant layout.

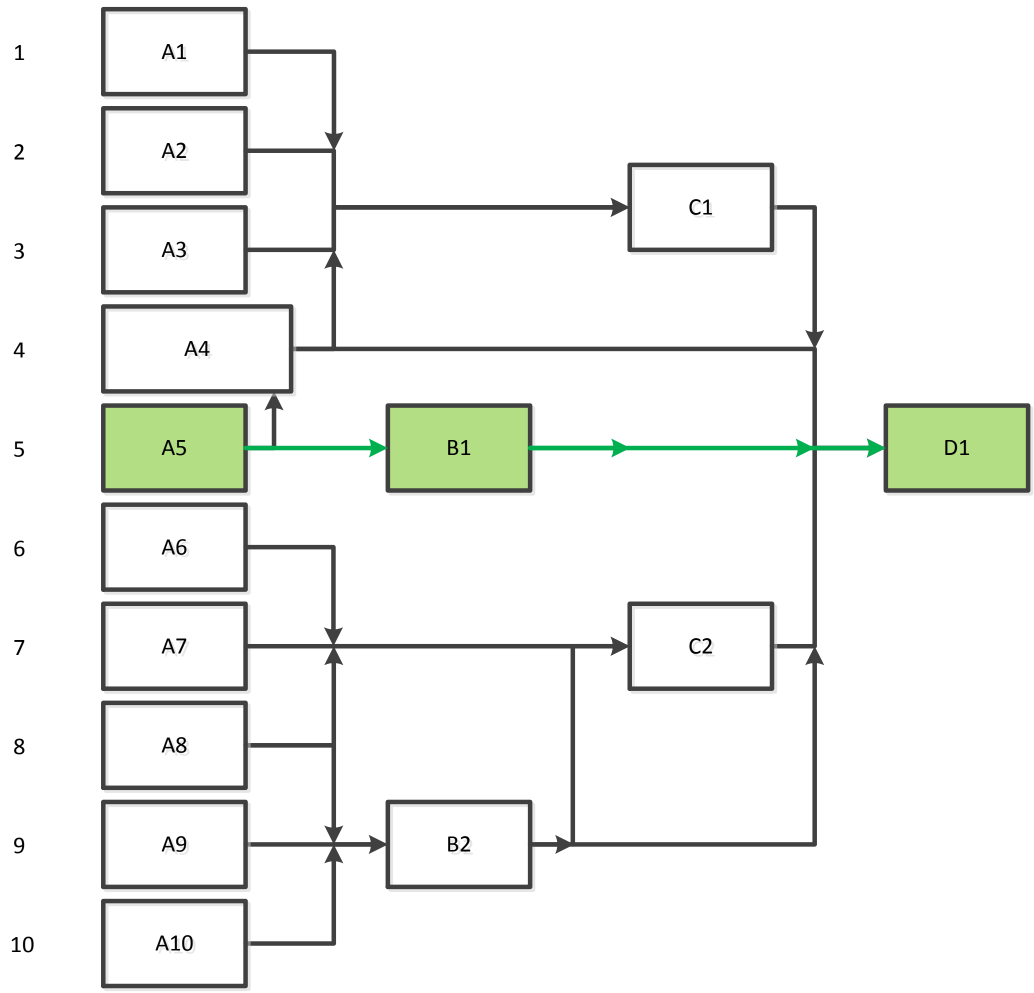


Figure 13. Functional layout for process line A5/B1/D1.

4.2.3 Administration table

An incident occurred when a person manoeuvring a pallet over the footpath bumped into a VA staff member working at the administration table. The administration table was placed so close to the footpath that it was causing a grievance to many. But, it was considered an unavoidable fact. The administration table was initially not included in the area under investigation and was outside the system boundary. But the researcher's opinion with regards to relocating the administration table was actively sought by staff, and, as such, he rose to the occasion to *work together* with staff to find a solution to the problem.

The freeing up of space on the plant floor as a result of moving process B1 gave rise to the idea of relocating the administration table. It was decided to move the administration table to the freed-up space (Figure 14a). The researcher proposed to move, along with the administration table, the rack used to store prepared boxes. The boxes were now closer to the processes for which they were prepared. Furthermore, the opportunity was seized by the researcher to instigate a re-assessment of the usefulness of position and size of other tables on the work floor. As a result, the processes A2, A3 table was shortened (Figure 14b). More space was created by changing the process B8 table (Figure 14c) and clustering the process B2 tables (Figure 14d).

The relocation of tables on the work floor is, in essence, an extension of the process prompted by the incident that occurred with the administration table. As such, it is part of the Shine and Standardise stage of the 5S methodology.

The researcher was delighted to see that staff approached him and asked for his opinion on how to deal with an issue they were trying to resolve. He considered it a confirmation that a certain level of trust had been reached. It should be noted that up to this point all implemented changes were reversible.

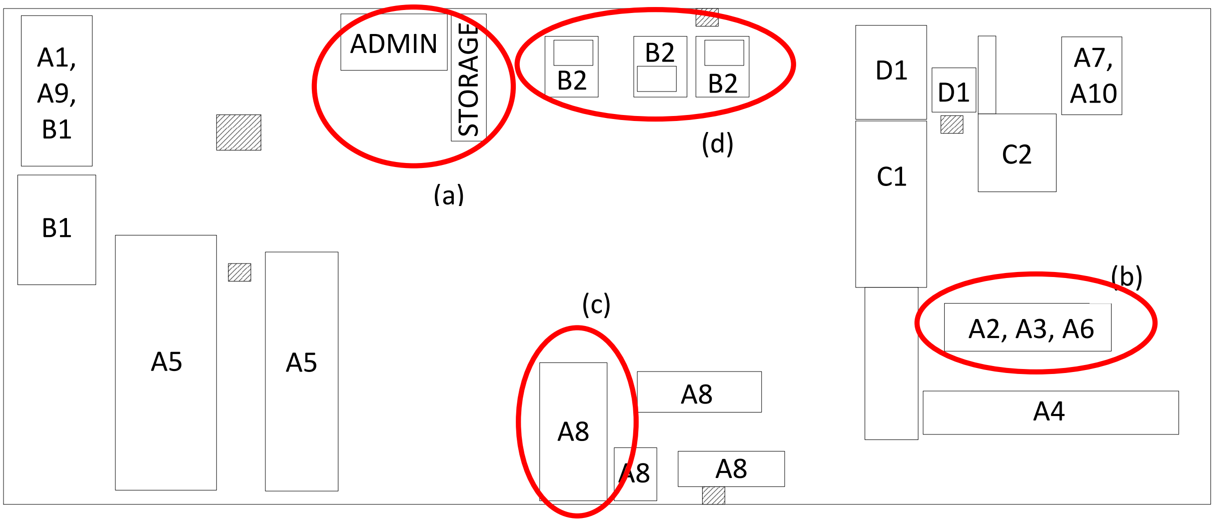


Figure 14. Relocation of administration table and box-rack.

4.3 Line balancing

4.3.1 Process line A8

Process A8 is part of process line A8/B2/C2/D1 (Figure 15). Process A8 is a cyclical process made up of multiple activities that are to be executed in a sequence under precedence constraints (Figure 16). The activities have the potential though, to be executed concurrently; depending on the number of in-line jigs and in-line guides, and on the number of operators on the line. In total there are 9 activities, namely:

1) Activity A8.1: Fill blocks
2) Activity A8.2: Load stick hopper
3) Activity A8.3: Stick guide loading
4) Activity A8.4: Place sticks
5) Activity A8.5: Load block
6) Activity A8.6: Cutting
7) Activity A8.7: Line dixie
8) Activity A8.8: Empty blocks
9) Activity A8.9: Stack on wheels

Out of these 9 activities, 2 activities, namely A8.3 and A8.6, are automated and have a fixed cycle time of 18.6 seconds and 26.0 seconds respectively.

Three operators were working on the process. It was observed that operator 1 was assigned to activity A8.1, operator 2 was assigned to activities A8.2 and A8.4, and operator 3 was assigned to activities A8.5, A8.7, A8.8, and A8.9. In practice it was found that operator 2 and operator 3 were sharing activity A8.5, and were often waiting for the other to complete the task. For the researcher this was an indication that the process might not be properly balanced. Time data on the individual activities was collected (Table 3), and the required sequence was determined (Figure 17). Furthermore it was observed that operator 3 was covering a lot more ground then operator 1 and operator 2. The distances traversed by each operator are captured in Figure 18.

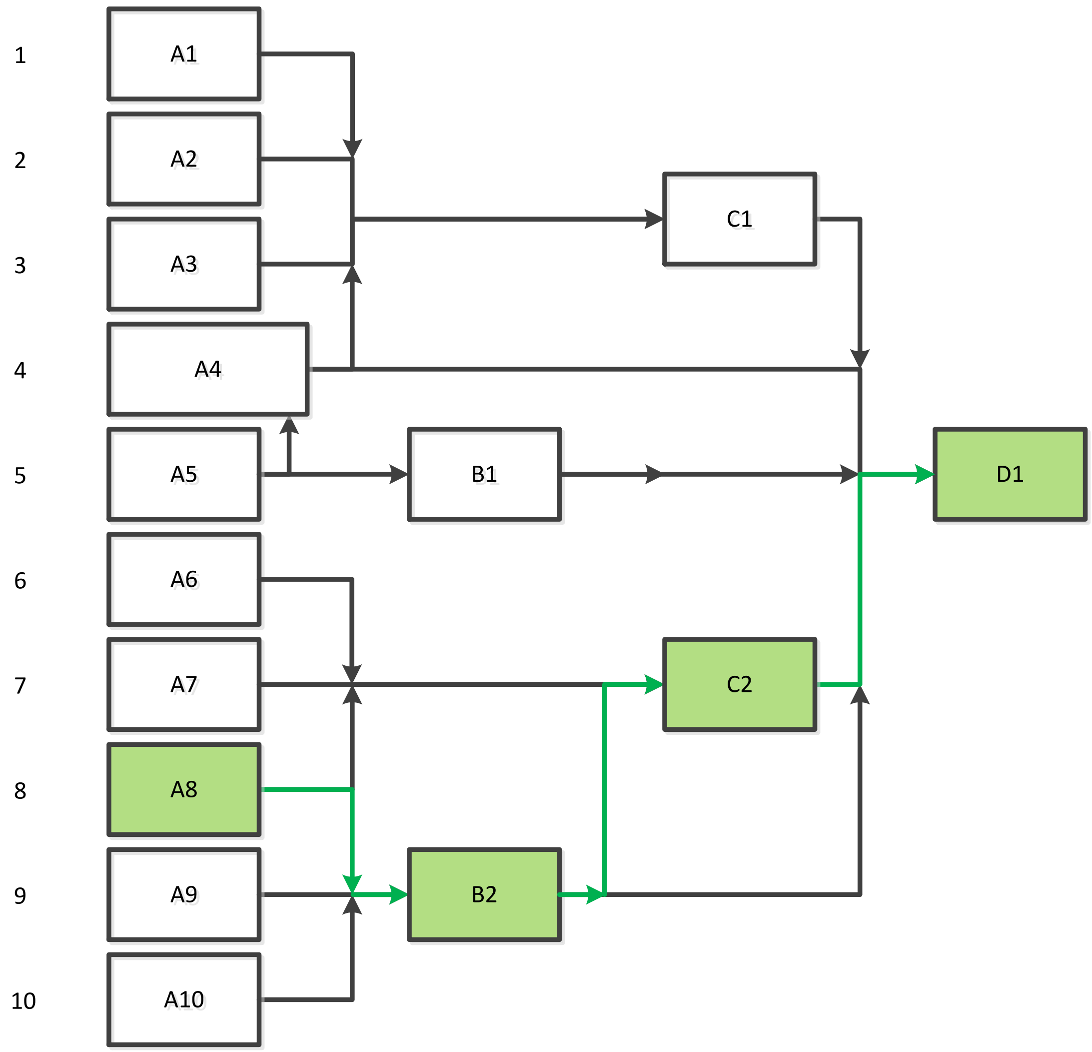


Figure 15. Functional layout for process line A8/B2/C2/D1.

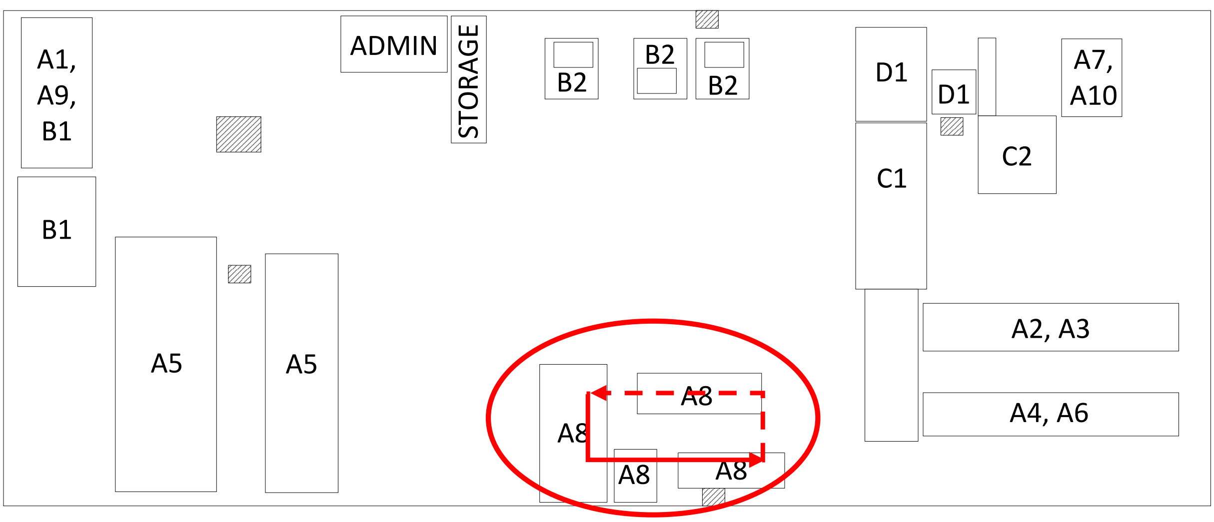


Figure 16. Spatial layout for process A8.

Table 3. Process A8 current state time measurement results

Operator	Activity	Duration [seconds]	Processing time [seconds]
1	A8.1	38	38
2	A8.2 A8.3 A8.4	4.8 18.6 9.8	33.2
3	A8.5 A8.6 A8.7 A8.8 A8.9	7.4 26 15 27.2 13.2	88.8

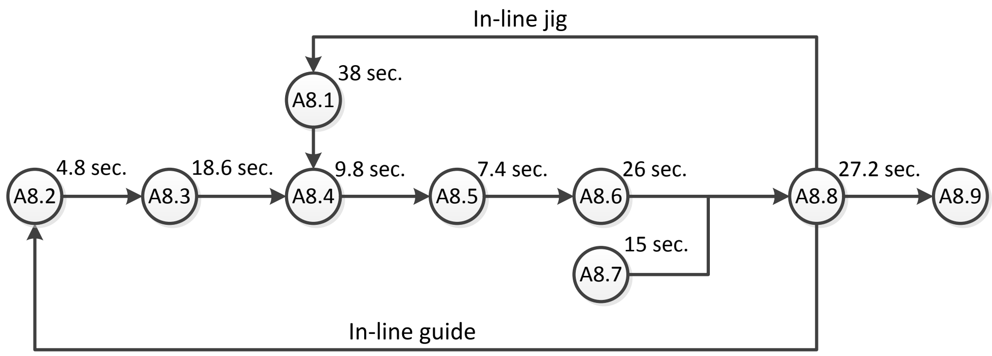


Figure 17. Precedence diagram for process A8: current state.

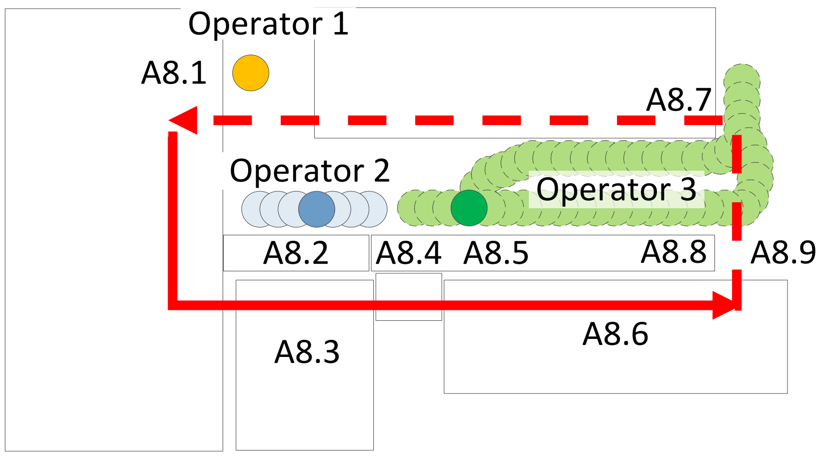


Figure 18. The current state spatial layout for process A8. Three operators, each represented by a different colour, are working on the proces. The lighter colours represent the path along which each operator was moving.

The starting point for conventional line balancing using a precedence diagram is determining the required cycle time for the process. For this particular process the cycle time is permenantly changing as a result of the process being part of an FMCG plant. The proper way forward would therefore be to optimise the process as much as we can.

In order to be able to take advantage of the possible executing of activites concurently - while adhering to imposed precedence contraints - the conventional line balancing technique of appropriatly grouping the activities presented in the precedence diagram does not provide a satisfactory solution. Note that the conventional technique neither gives insight into the amount of in-line jigs and in-line guides required to run the process efficiently, nor does it take into consideration that all activities are executed twice per cycle, exept activities A8.7 and A8.9, which are executed only ones per cycle.

In order to predict the efficacy of proposed changes to the Cyclical Process with Concurrent Activities (CPCA), a chart was devised to capture time, activity, number of operators, number of in-line jigs and in-line guides, and sequentiality. The chart will henceforth be referred to as a CPCA chart.

The first step taken was to choose a convenient scale for the x and y-axis. Time was assigned to the x-axis, while the activities were assigned to the y-axis. Also included in the chart was a legend explaining which colours were assigned to individual operators and machines (Figure 19). Next step was to assign activities to individual operators according to the current state of the process, and place them on the chart according to precedence and constraints. For example, operator 1 was assigned to activity A8.1, which takes 38 seconds to complete. Operator 2 was assigned to activities A8.2, A8.3, and A8.4. Of which activity A8.3 is automated and taking 18.6 seconds to complete, while activities A8.2 and A8.3 take 4.8 seconds, and 9.8 seconds to complete respectively. Note that activity A8.2 should be completed prior to A8.3. Activity A8.4 can only commence when A8.3 and A8.1 have completed (Figure 20). The assigning of activities was continued until a complete cycle was assigned (Figure 21).

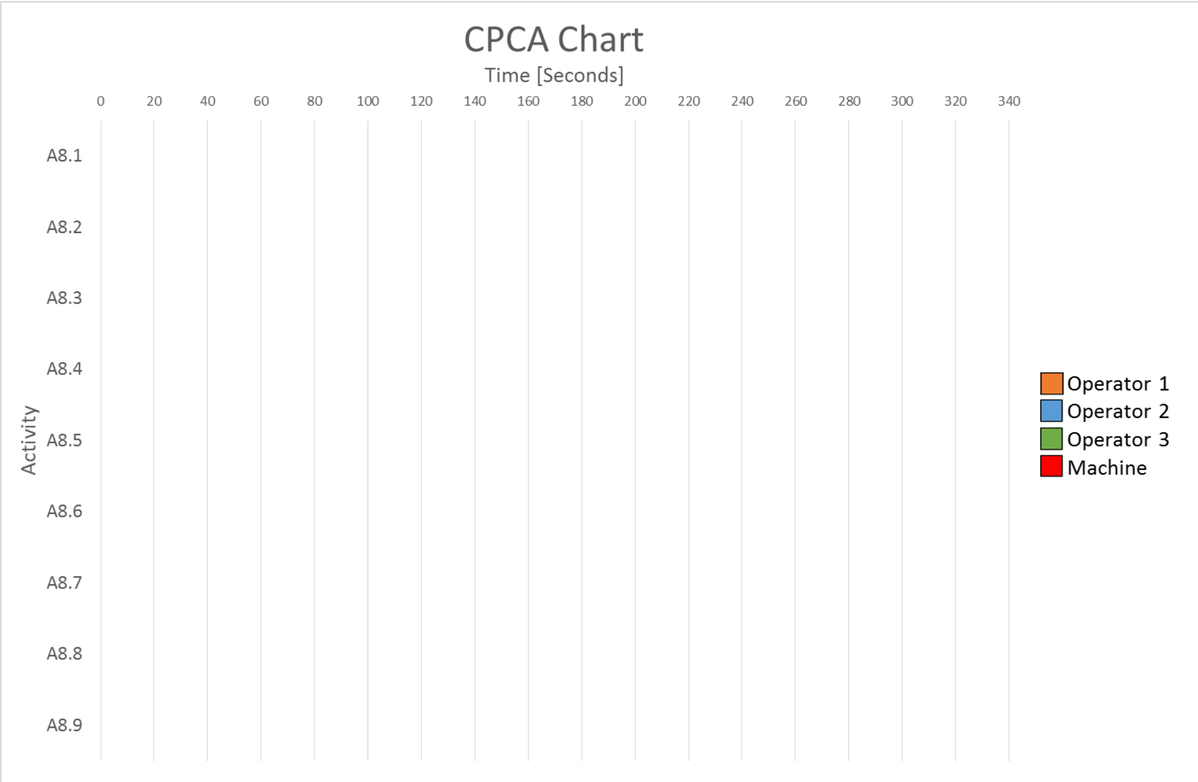


Figure 19. CPCA chart layout

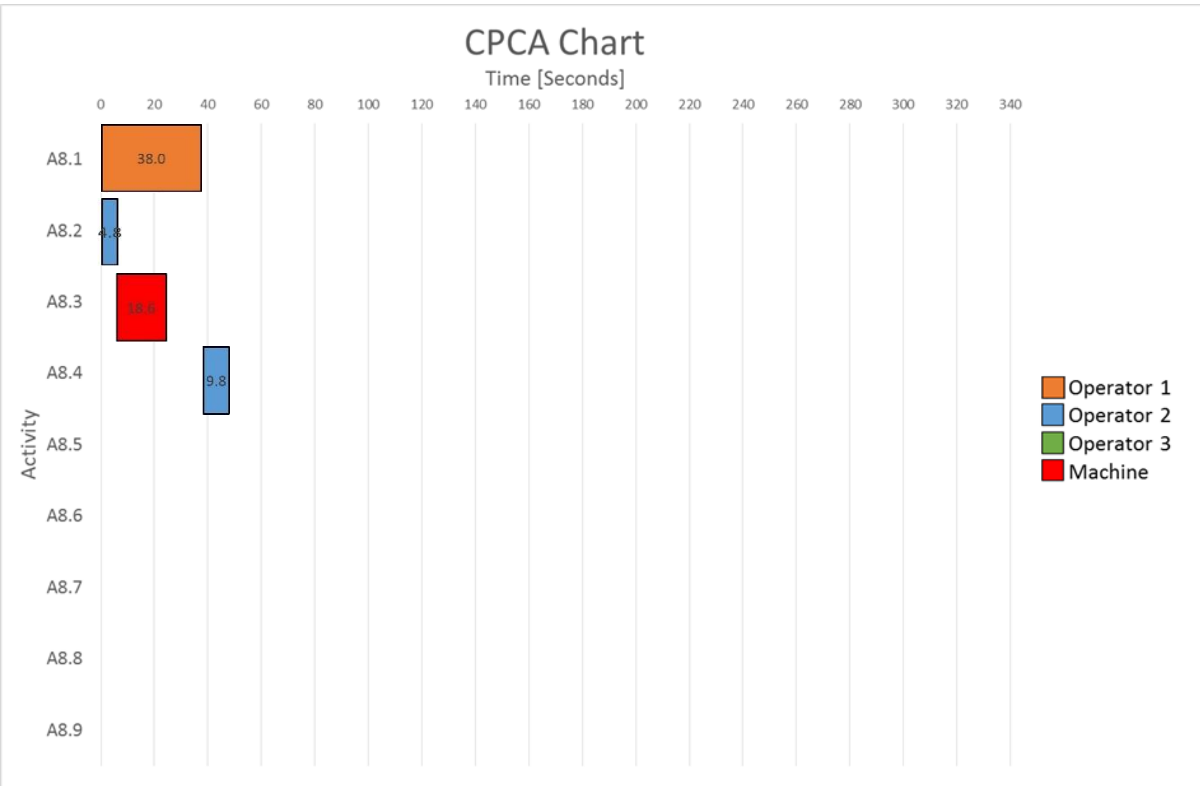


Figure 20. Assigning activities to the CPCA chart

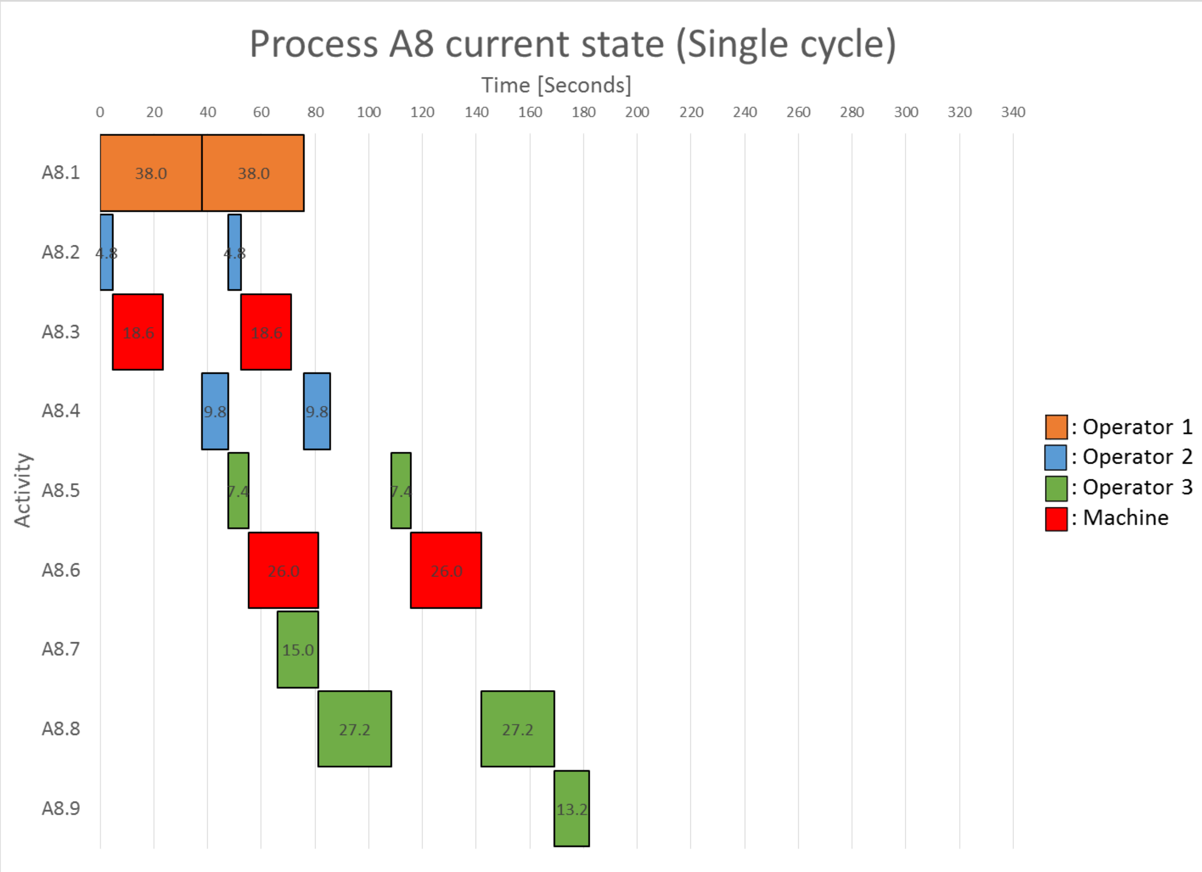


Figure 21. Current state sequence for one complete cycle for process A8.

Once a full cycle is allocated, the cycle is duplicated and positioned folowing on from the previous cycle. For this particular process it now becomes evident why task A8.5 was shared between operator 2 and operator 3. It is clear a clash exists when operator 2 tries the complete the second cycle: activity A8.5 coincides with activity A8.8 (Figure 22).

Continuing with assigning activities while making sure clashes are avoided results in a chart for the current state process A8 in steady state (Figure 23). From this chart we can deduce the following:

- Expected process cycle time of 135 seconds per two blocks
- The process requires a minimum of six in-line jigs
- The process requires a minimum of six in-line guides
- Cycle time for operator 1 is 38 seconds
- Cycle time for operator 2 is 14.6 seconds
- Cycle time for operator 3 is 49.6 seconds and 47.8 alternately

Ofcource the process can not be maintained this way because operator 3 is constantly lagging. That is why in practise we see the sharing of activity A8.5. But even sharing A8.5 does not balance the line and as a result no flow exists and operator 2 and operator 3 are constantly waiting for the other to finish activity A8.5.

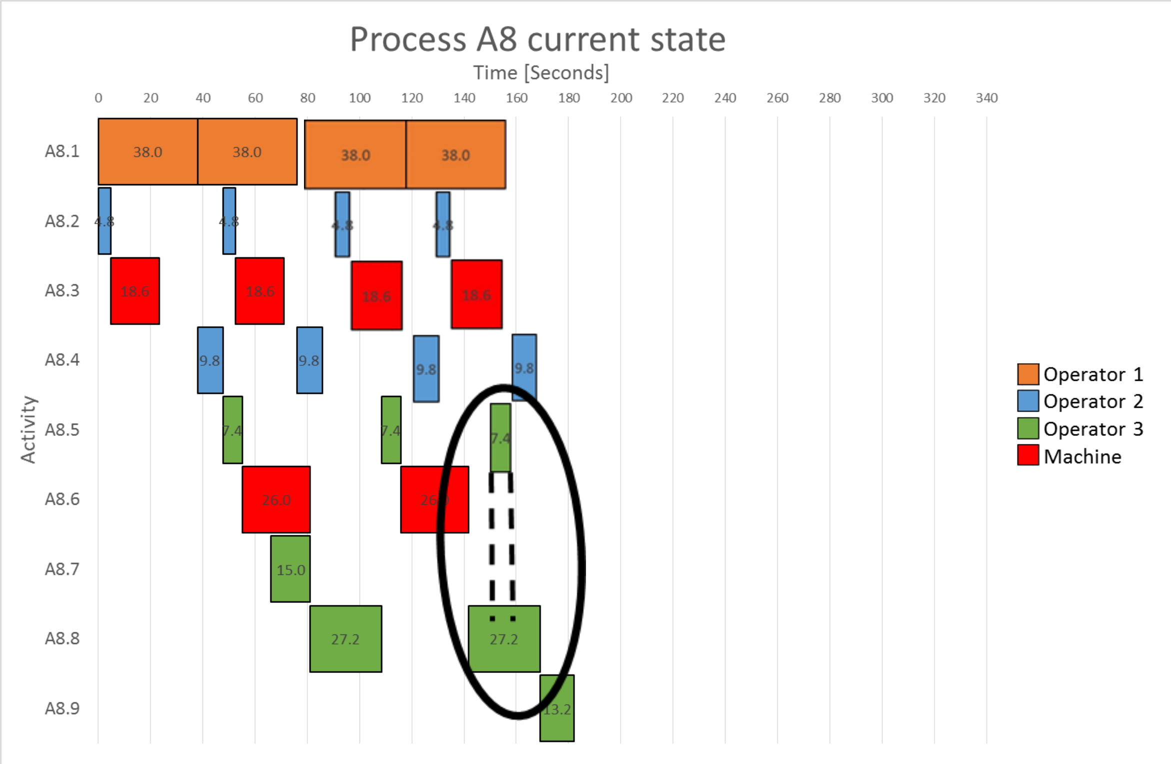


Figure 22. The reasin for sharing of activity A8.5 between operator 1 and operator 2: a clash exists between activity A8.5 and activity A8.8.

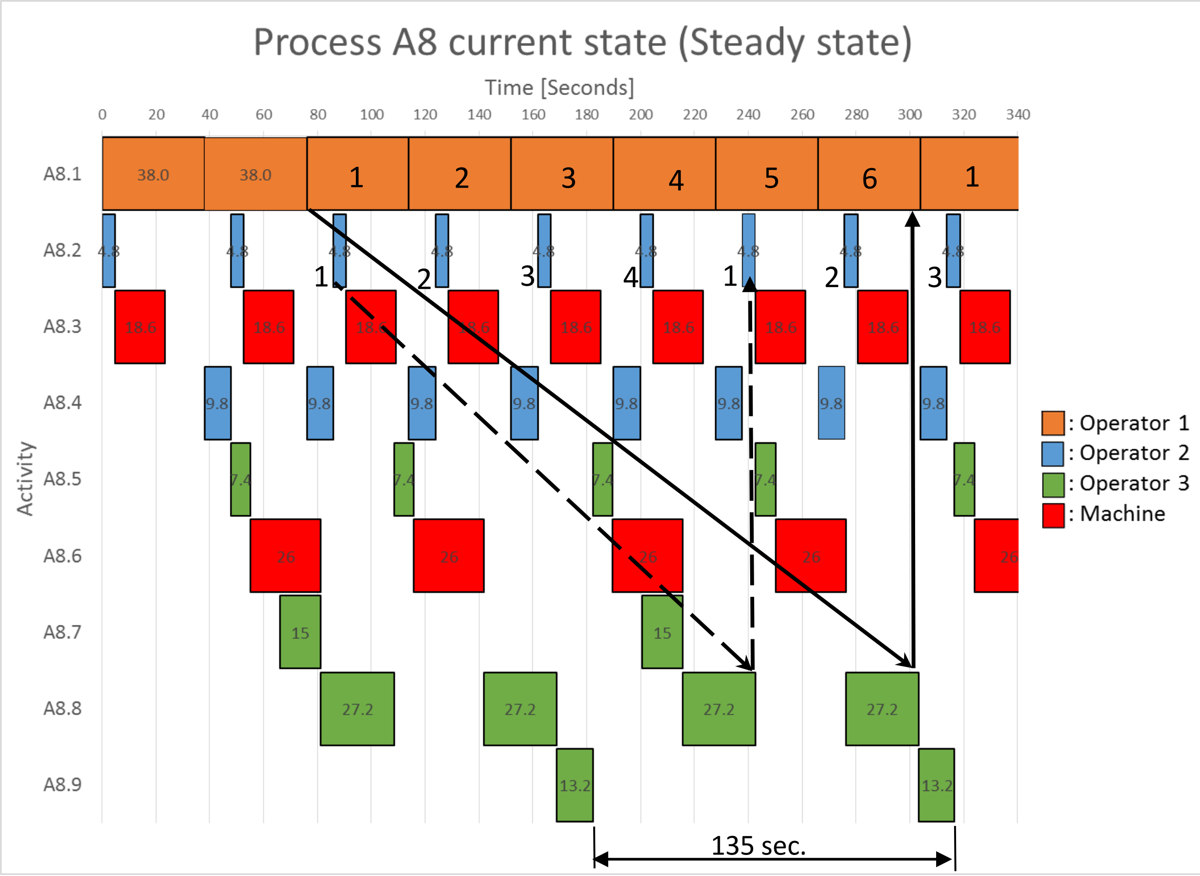


Figure 23. Current state sequence for process A8: Steady state. From the figure we can deduce the process requires six jigs and four guides. Two blocks are produced every 135 seconds. The process requires three operators assigned to the tasks as indicated by the colour coding.

In order to balance the workload, the workload for operator 2 needs to increase and the workload for operator 3 needs to decrease. An obvious contender to be assigned to operator 2 was activity A8.5: increasing the workload for operator 2 from 14.6 seconds to 22 seconds, and decreasing the workload for operator 3 from 62.8 seconds to 55.4 seconds. This would still leave a difference of 33.4 second between the two workloads.

The only next activity that could be a contender, based on the spatial layout of the process, was activity A8.8. Assigning activity A8.8 in its entirety to operator 2 would not work, and therefore the researcher looked at dividing the activity in two. Activity A8.8 was divided in activity A8.8.1 and activity A8.8.2 (

Figure 24), naming them 'Unload Block' and 'Empty Block' respectively. Time measurements were taken, and the observed times are presented in Table 4.

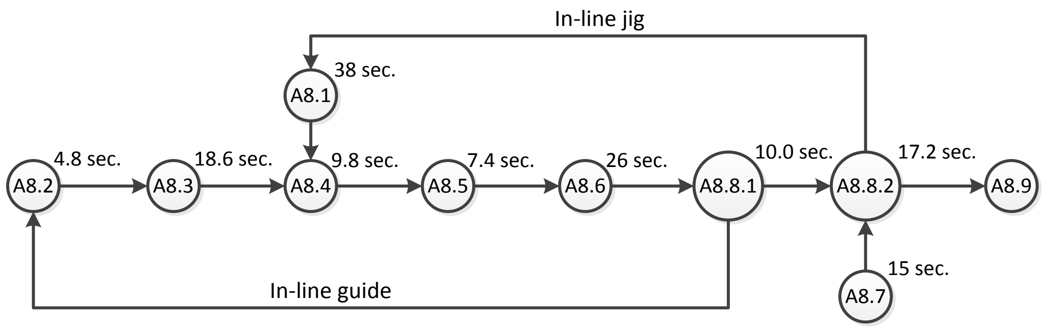


Figure 24. Precedence diagram for process A8: future state.

Table 4. Process A8 future state time predictions

Operator	Activity	Duration [seconds]	Processing time [seconds]
1	A8.1	38	38
2	A8.2	4.8	
	A8.3	18.6	
	A8.4	9.8	
	A8.5	7.4	
	A8.6	26	
	A8.8.1	10	76.3
3	A8.7	15	
	A8.8.2	17.2	
	A8.9	13.2	45.4

We can now set up a future state CPCA chart for the process. Following the same methodology as for the current state CPCA chart, we first devise a chart for a single cycle (Figure 25), and then a chart for steady state (Figure 26). From the chart (Figure 27) we can deduce the following:

- Expected process cycle time of 105 seconds per two blocks
- The process requires a minimum of four in-line jigs
- The process requires a minimum of two in-line guides
- Cycle time for operator 1 is 38 seconds
- Cycle time for operator 2 is 32 seconds
- Cycle time for operator 3 is 32.2 seconds and 30.4 alternately

To be able to obtain these results the process layout will have to be adjusted such that operator 2 can execute the newly assigned tasks. The Process layout will have to be changed from an L-shape configuration to a U-shape configuration (Figure 28). Process A8 will take up a position on the plant floor as proposed in Figure 29.

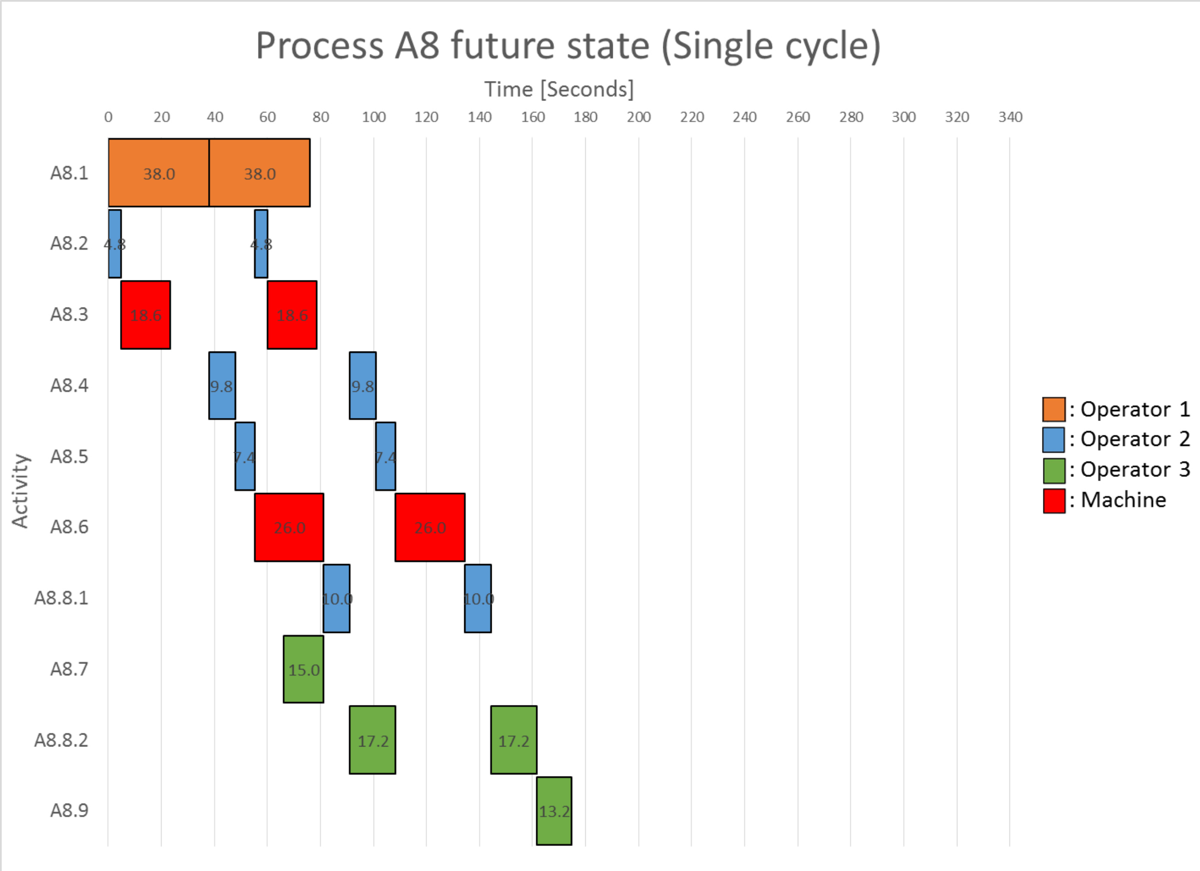


Figure 25. Future state sequence for one single completed cycle for process A8.

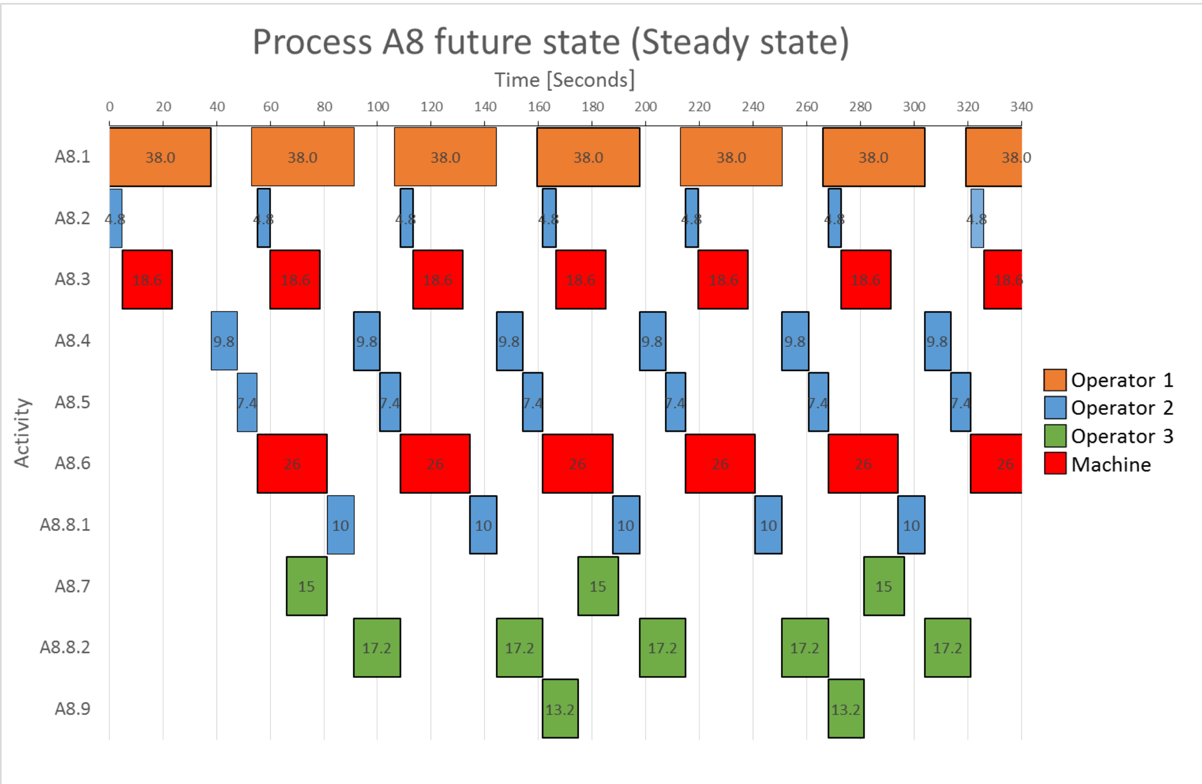


Figure 26. Future state sequence for process A8: Steady state.

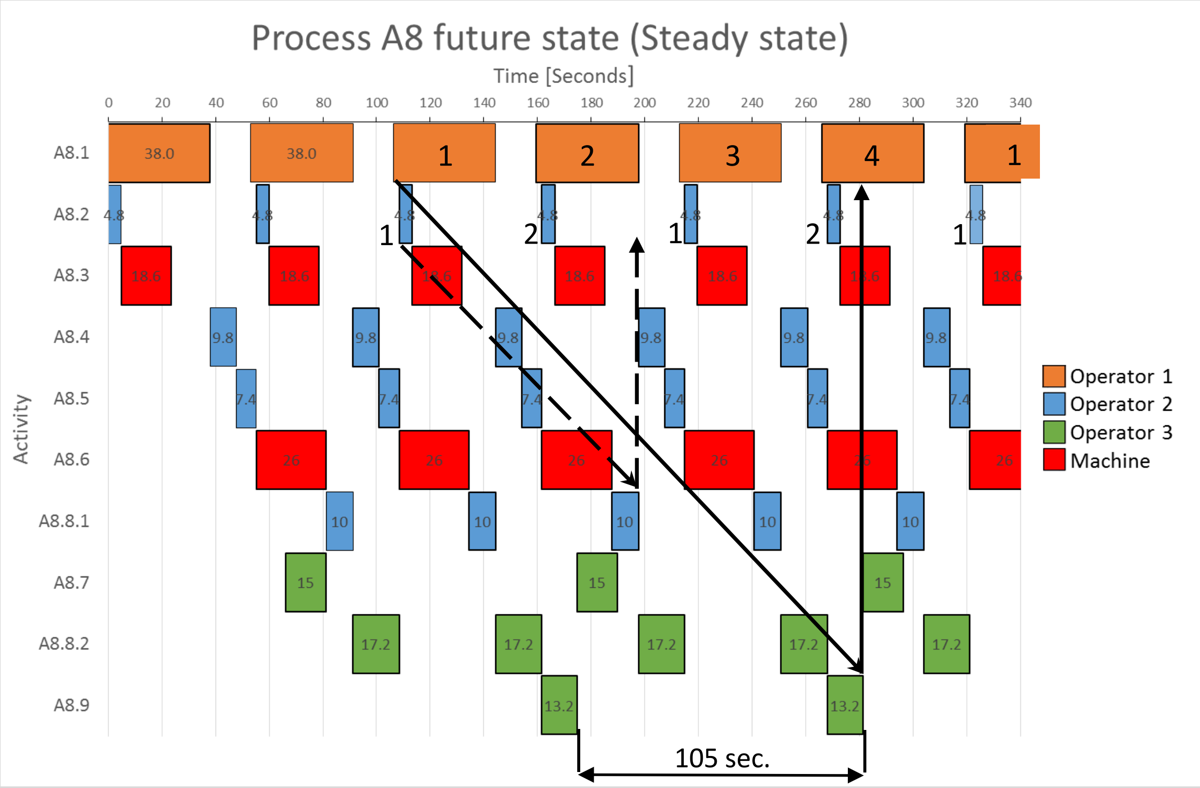


Figure 27. Future state sequence for process A8: Steady state, CPCA analysis. From the figure we can deduce the process requires four jigs and two guides. Two blocks are produced every 105 seconds. The process requires three operators assigned to the tasks as indicated by the colour coding.

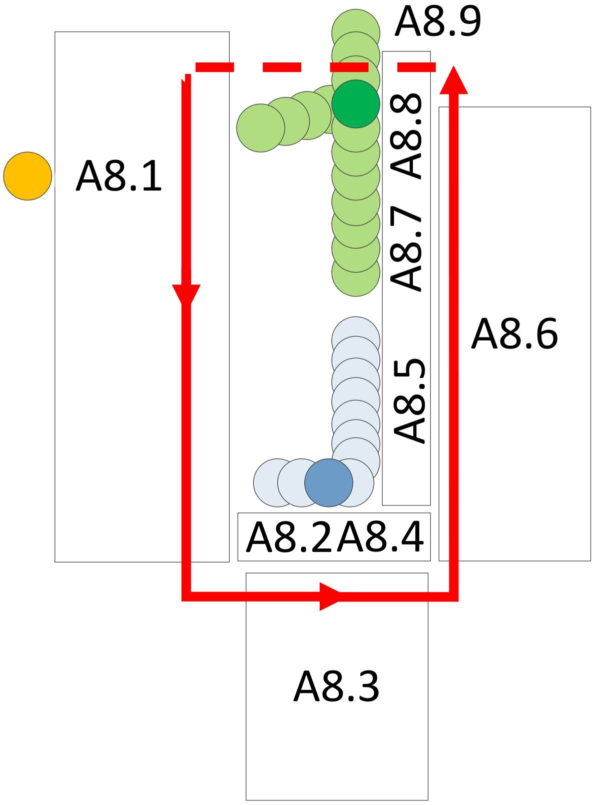


Figure 28. The future state layout for process A8. The circles represent the movement of an operator working on the process. Each operator is represented by a colour.

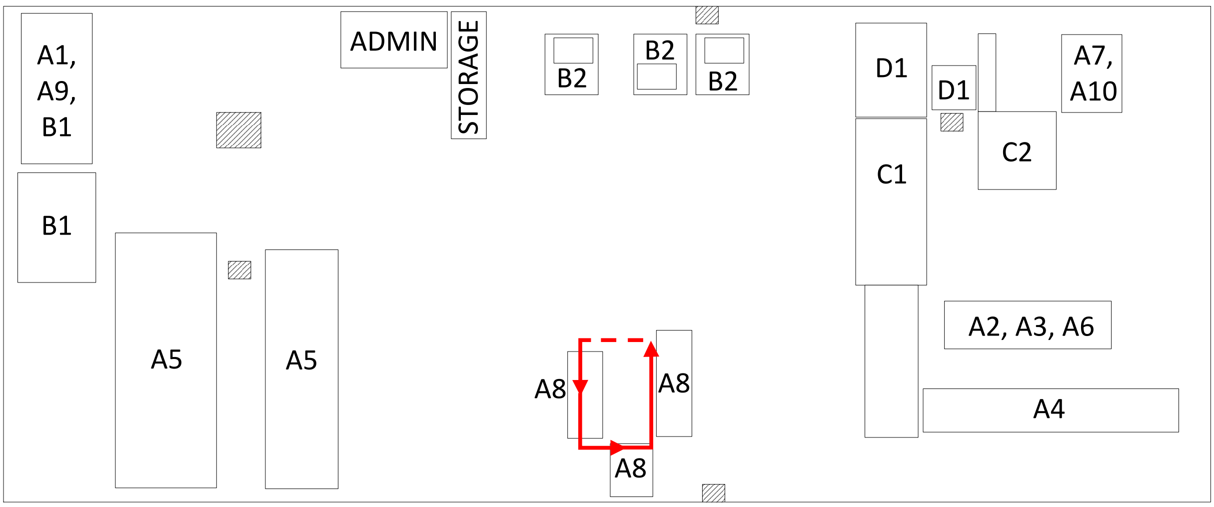


Figure 29. Redesigned process A8 layout.

4.4 VSM

4.4.1 Process line B2/C2/D1

As can be seen from the functional layout of the plant (Figure 15), process B2 feeds into process C2. As indicated by the spatial layout for process B2/C2 (Figure 30) a significant physical distance existed between process B2 and the subsequent process C2. On grounds of having to process a bulk product that was send off to the next department via interdepartmental conveyor without going through process C2, all process B2 processing was done close to the interdepartmental conveyor. This way of processing required adding plastic liners to product before it was placed in a box. Boxes were than stacked and stored on the floor awaiting transport to process C2 for further processing. The liners were used once and then discarded (Figure 31).

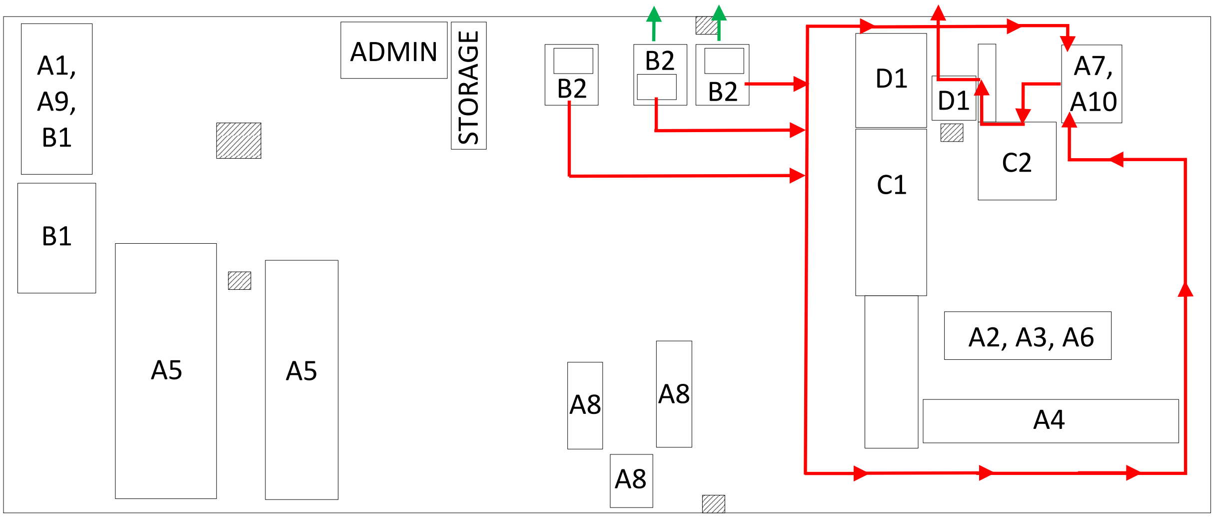


Figure 30. The spatial layout signifying the physical distance between process B2 and C2. The red arrows represent the path the product was travelling to reach process C2 proir to intervention. The green arrows represent the path the bulk product was travelling.

Figure 31. Process C2 prior to intervention. Note the use of plastic liner when the box is traveling along with its content.

Based on the findings obtained from analysing the spatial layout for process B2/C2, VSMs were drawn up capturing the current state (Figure 32) and a future state (Figure 33) for the process. VSMs were then used to instigate a discussion between the researcher and the team leader of the plant. After careful deliberation, the team leader agreed to have the researcher run a trial to demonstrate the effects of eliminating the activities B2.3, B2.4, and C1.1. The trial rig set-up was as shown in Figure 34. Pre-intervention the process had a value added time of 22.5 seconds/tray, necessitated the use of WIP, and required the use of plastic liners. The improved process was expected to have a value added time of approximately 17.5 seconds/tray, a significant reduction of WIP, and a complete elimination of the plastic liner used in the process. A conveyor required for the trial was recovered from storage and modified by the engineering department to make it fit for purpose. Process B2 for bulk product was still done close to the interdepartmental conveyor on a designated table (Figure 13).

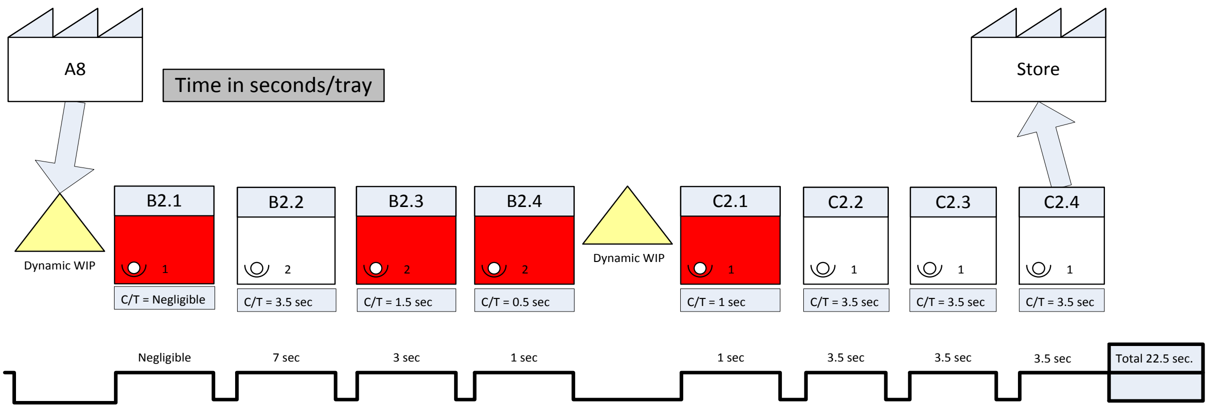


Figure 32. Current state VSM: Process line B2/C2/D1.

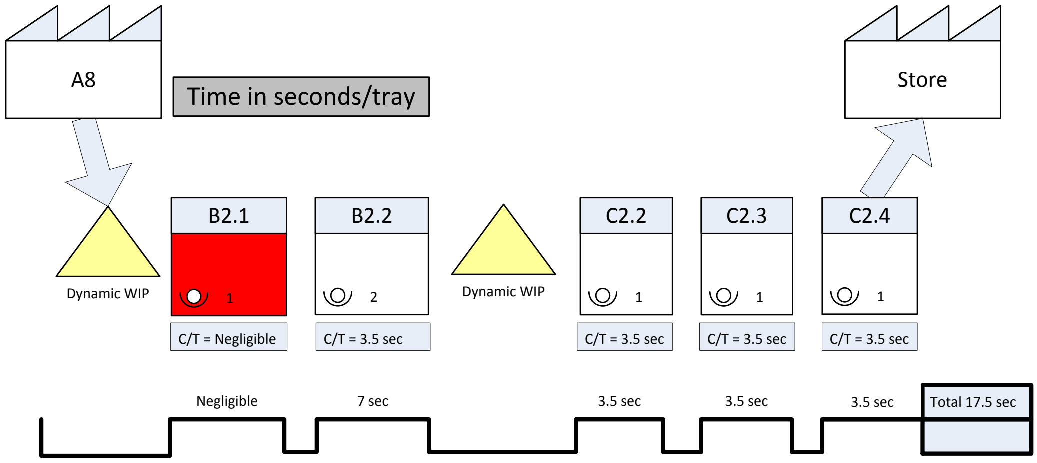


Figure 33. Future state VSM: Process line B2/C2/D1.

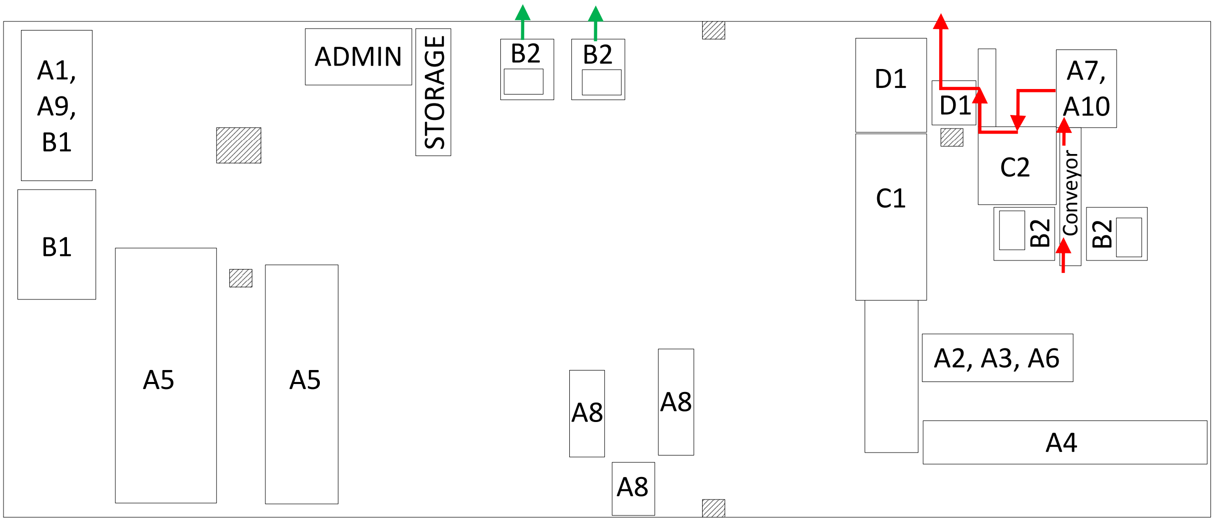


Figure 34. The spatial layout signifying the physical distance between process B2 and C2. The red arrows represent the path the product from B2 was travelling to reach process C2 post intervention. The green arrow represent the path the bulk product was travelling.

The day prior to the trial a meeting was held in which the team leader and the researcher introduced to staff the intention to run the trial. The trial was conducted using a conveyor to link process B2 with process C2 (Figure 35).

Figure 35. The process B2/C2/D1 after intervention. Note the box is married up with its content at the very end of the process, not requiring any plastic liner.

As a result of the positive trial-run the trial was extended to last for the remainder of the week during which the researcher assisted staff in becoming familiar with the new layout. The week-long trial confirmed the new way of processing was superior to how it was done in the past and the conveyor became a permanent fixture in the plant.

4.4.2 Process line A6/C2/D1

In order to analyse process A6 a current state VSM was drawn up (Figure 38). From the current state VSM it was deduced that, besides having a non-value adding activity in the form of the stacking activity in the process, the line was not well balanced. The times per activity were compared, and a future state VSM was drawn up (Figure 39). It was concluded that, in order to balance the line, the stacking activity had to be removed from the process. A spreadsheet was set up to calculate the effect of the elimination of the stacking activity (Table 5), and the results were plotted in a graph (Figure 40).

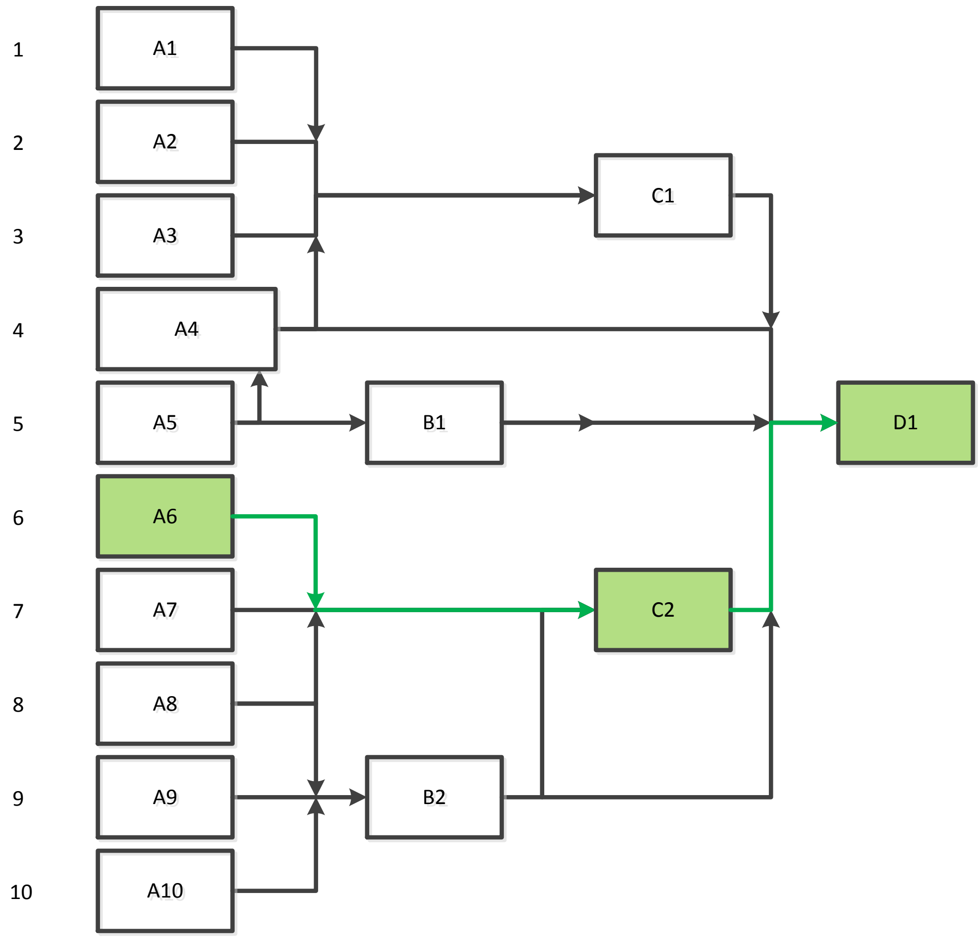


Figure 36. Functional layout for process line A6/C2/D1.

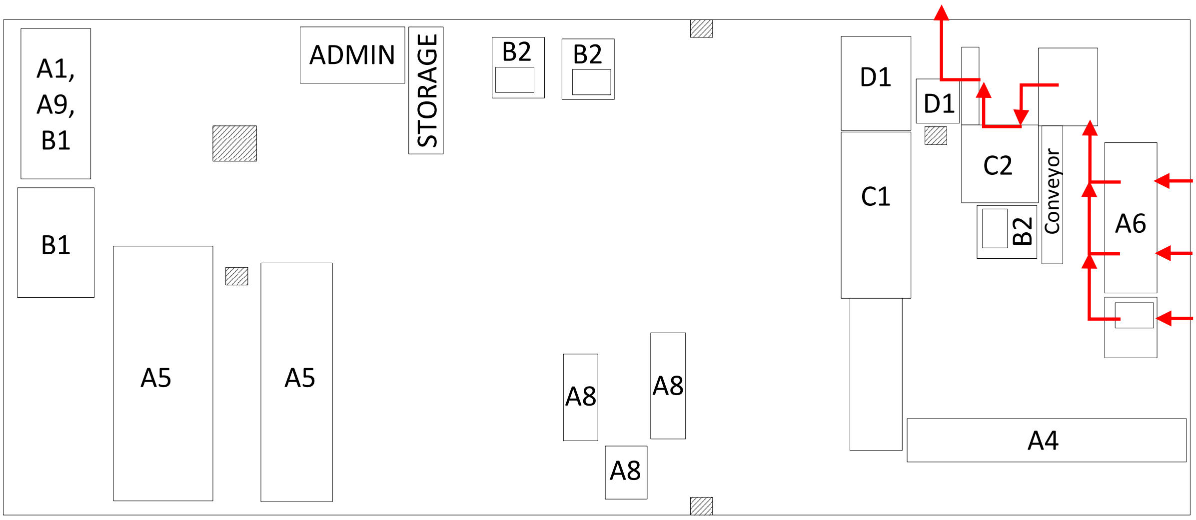


Figure 37. Spatial layout for process line A6/C2/D1.

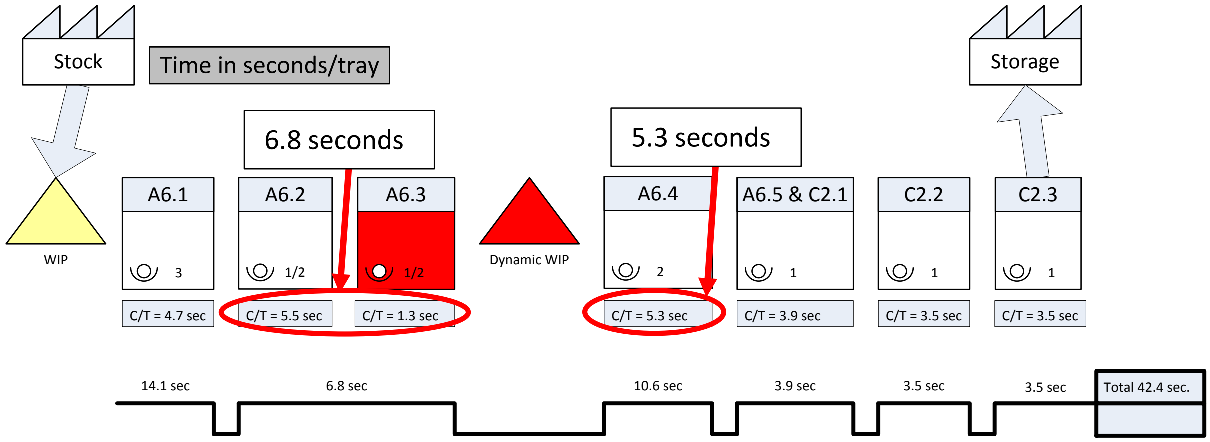


Figure 38. Current state VSM: Process line A6/C2/D1.

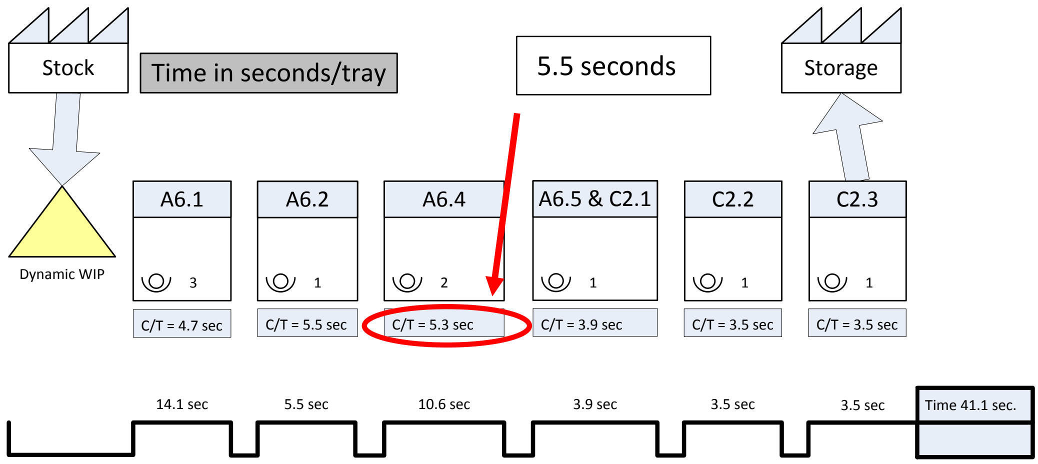


Figure 39. Future state VSM: Process line A6/C2/D1

Table 5. Calculation for process line A6/C2/D1 processing times for current and future state.

	Current state							Future state		
	Pre buffer			Post buffer			Sum			
Volume [Trays]	C/T [sec]	C/T [hrs]	Time [hrs], # Staff (4)	C/T [sec]	C/T [hrs]	Time [hrs], # Staff (5)	Time [hrs], # Staff (9)	C/T [sec]	C/T [hrs]	Time [hrs], # Staff (9)
0	0	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00
10	68	0.02	0.08	53	0.01	0.07	0.15	55	0.02	0.14
20	136	0.04	0.15	106	0.03	0.15	0.30	110	0.03	0.28
30	204	0.06	0.23	159	0.04	0.22	0.45	165	0.05	0.41
40	272	0.08	0.30	212	0.06	0.29	0.60	220	0.06	0.55
50	340	0.09	0.38	265	0.07	0.37	0.75	275	0.08	0.69
60	408	0.11	0.45	318	0.09	0.44	0.90	330	0.09	0.83
70	476	0.13	0.53	371	0.10	0.52	1.04	385	0.11	0.96
80	544	0.15	0.60	424	0.12	0.59	1.19	440	0.12	1.10
90	612	0.17	0.68	477	0.13	0.66	1.34	495	0.14	1.24
100	680	0.19	0.76	530	0.15	0.74	1.49	550	0.15	1.38

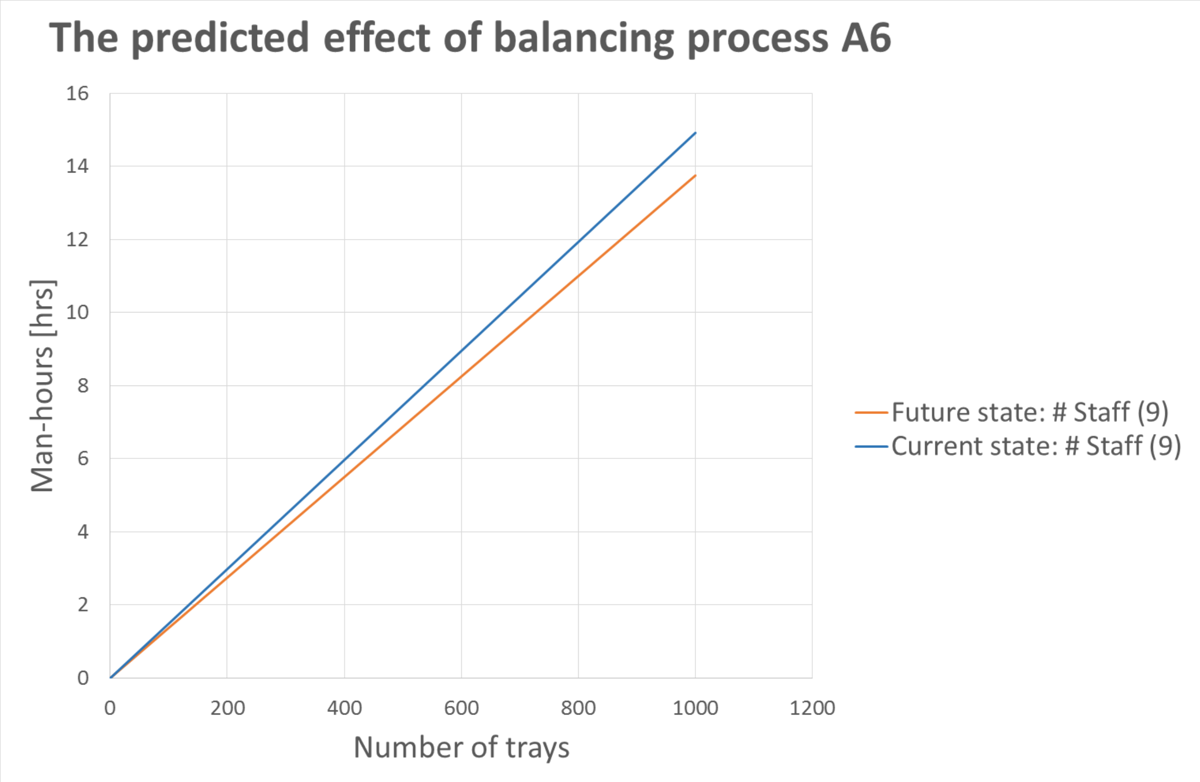


Figure 40. Total amount of labour hours spent per number of trays on process line A6/C2/D1.

From Figure 40 it can be deduced that the expected outcome of executing the wrapping process as proposed in the future state VSM would result in an approximate 7% reduction in labour hours/per tray. Taking the 130,000 trays processed during the FY to date as an estimation for future volumes, the saving per year on labour would be approximately $4000.00.

4.4.3 Process line A5/A4/C1/D1

The product groups 6, and 10 were processed on line A5/A4/C1/D1. The only major difference between the product groups was that group 6 required additional activity A4.1: group 10 did not. As can be seen from the functional layout of the plant (Figure 41), process A4 feeds into process C1. As indicated by the spatial layout for process A4 (Figure 42) a significant physical distance existed between process A4 and the interdepartmental conveyor. On grounds of having to process tray packed products, all process A4 processing was done close to process C1. This way of processing required extra movement of stock, and an increased amount of WIP on the floor when processing bulk.

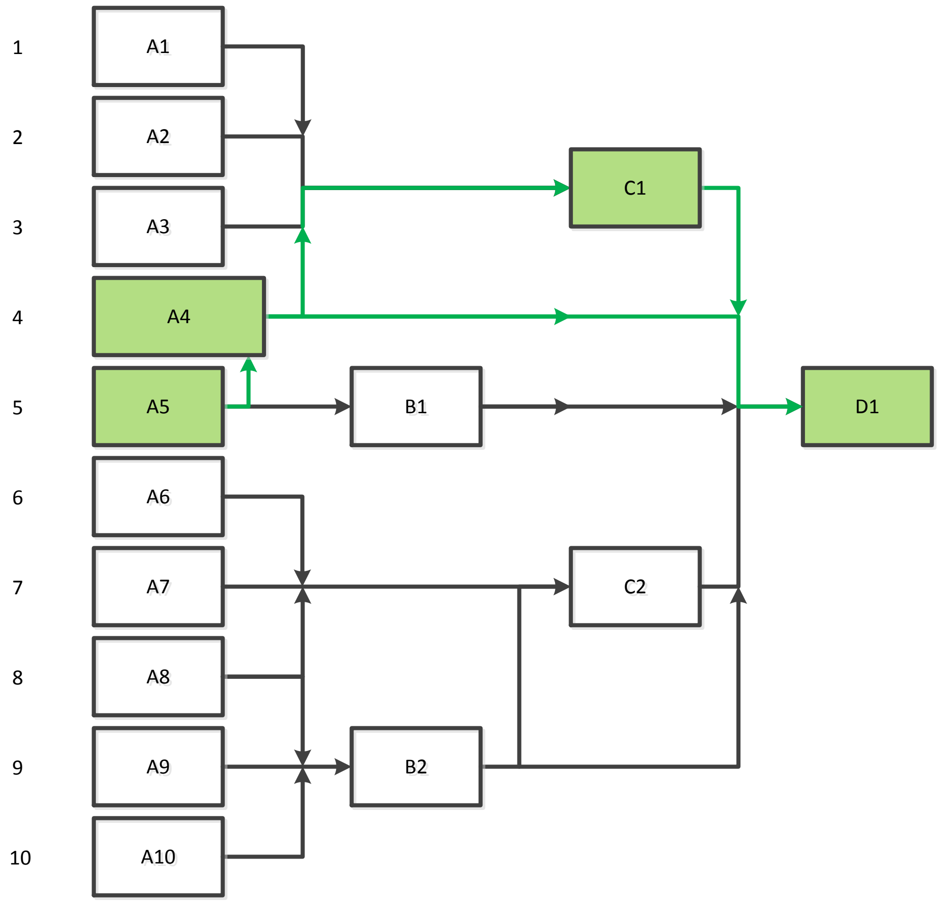


Figure 41. Functional layout for process line A5/A4/C1/D1.

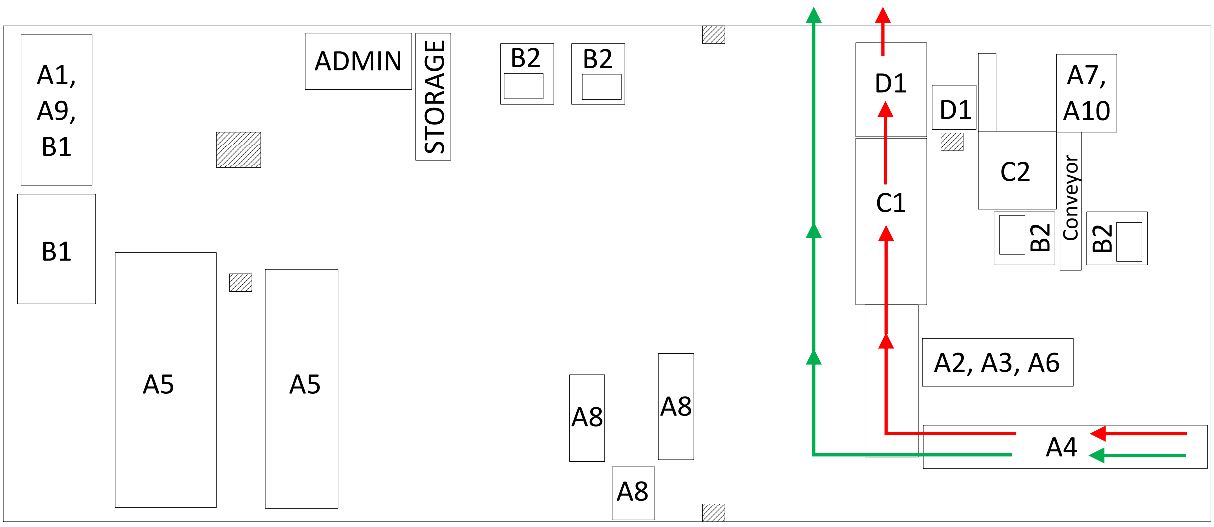


Figure 42. The spatial layout for process line A4/C1/D1. The red arrows represent the path the product from A4 was travelling to reach process C1 prior to intervention. The green arrows represent the path the bulk product was travelling.

Based on the findings obtained from analysing the spatial layout for process A4 VSMs were drawn up capturing the current state (Figure 43) and a future state (Figure 44) for the process. VSMs were then used to instigate a discussion between the researcher and the team leader of the plant.

From the current state VSM it was deduced that, besides having a non-value adding activity in the form of activity A4.6 in the process, the line was not well balanced. The times per activity were compared, and a future state VSM was drawn up (Figure 44). It was concluded that, when activity A4.1 is included, 8 staff members needed to be working on the line in order to balance it. Initially there were 4 staff members working on the line. Thus, by doubling the number of staff on the line — from 4 to 8 — the time to process one tray was expected to be reduced to roughly a third — from 12 seconds to 4.3 seconds. A spreadsheet was set up to calculate the effect of increased staff and reduced process cycle time (Table 6), and the results were plotted in graph. As can be seen form Figure 45, although the number of staff would increase, the total amount of man-hours spent on the process was expected to decrease.

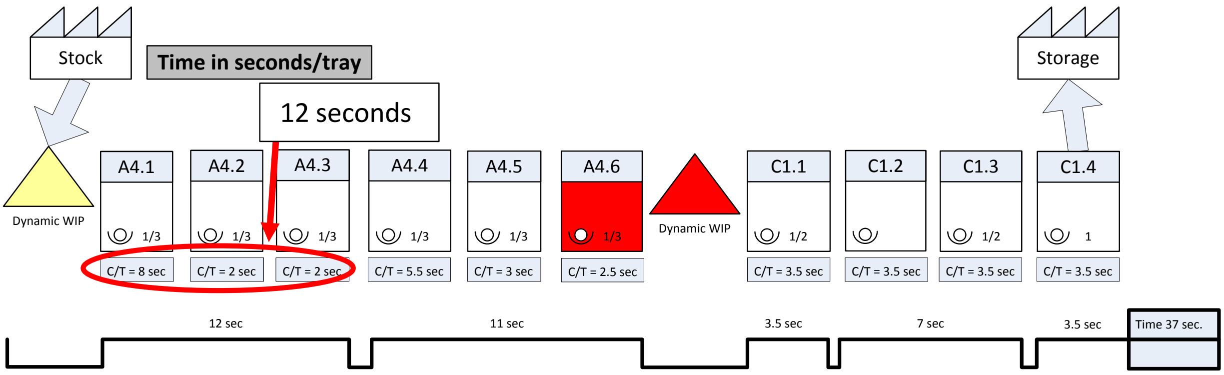


Figure 43. Current state VSM: Process line A4/C1/D1 (including activity A4.1).

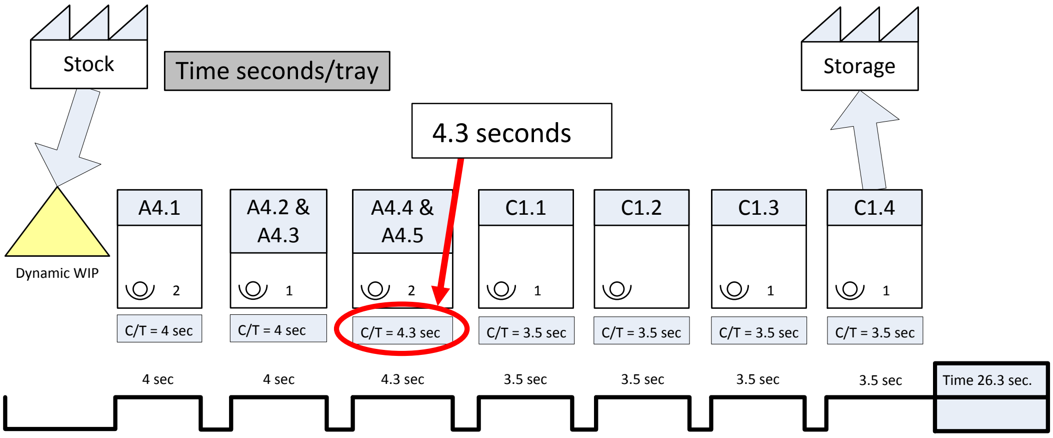


Figure 44. Future stateVSM: Process line A4/C1/D1 (including activity A4.1).

Table 6. Calculation for process line A4/C1/D1 processing times for current and future state (including activity A4.1).

	Current state (Including A4.1)				Future state (Including A4.1)		
Volume [Trays]	C/T [sec]	C/T [hrs]	Time [hrs], # Staff (4)		C/T [sec]	C/T [hrs]	Time [hrs], # Staff (8)
0	0	0.00	0.00		0	0.00	0.00
10	120	0.03	0.13		43	0.01	0.10
20	240	0.07	0.27		86	0.02	0.19
30	360	0.10	0.40		129	0.04	0.29
40	480	0.13	0.53		172	0.05	0.38
50	600	0.17	0.67		215	0.06	0.48
60	720	0.20	0.80		258	0.07	0.57
70	840	0.23	0.93		301	0.08	0.67
80	960	0.27	1.07		344	0.10	0.76
90	1080	0.30	1.20		387	0.11	0.86
100	1200	0.33	1.33		430	0.12	0.96

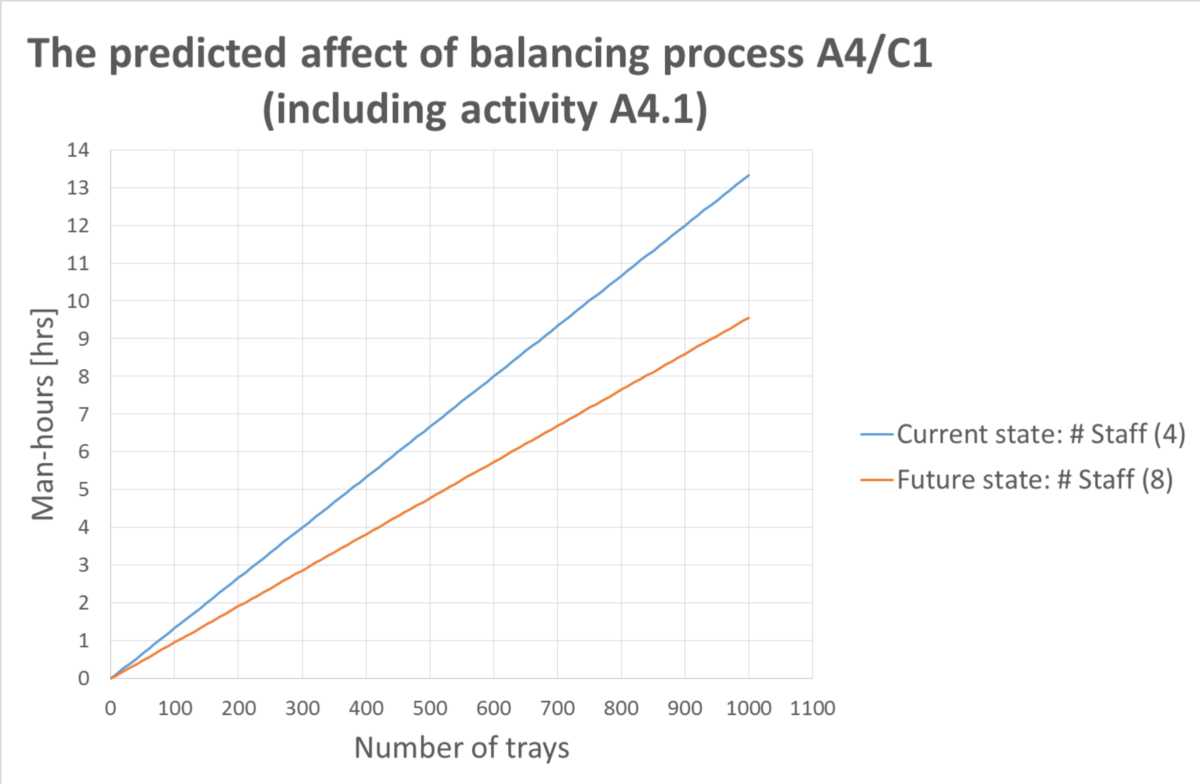


Figure 45. Total amount of man-hours spent per number of trays on process A4 (including activity A4.1).

From Figure 45 it can be deduced that the expected outcome of executing process A4 as proposed in the future state VSM would result in an approximate 35% reduction in man-hours /per tray. A similar approach was taken to analyse the A4 process excluding activity A4.1. A current state VSM (Figure 46) and a future state VSM (Figure 47) were drawn up. A spreadsheet was set up to calculate the effects of the intervention (Table 7), and the results were plotted in a graph (Figure 48). Again it was found that increasing the number of staff on the line would result in a reduction of the process cycle time as well as a reduction of man-hours spent on the process.

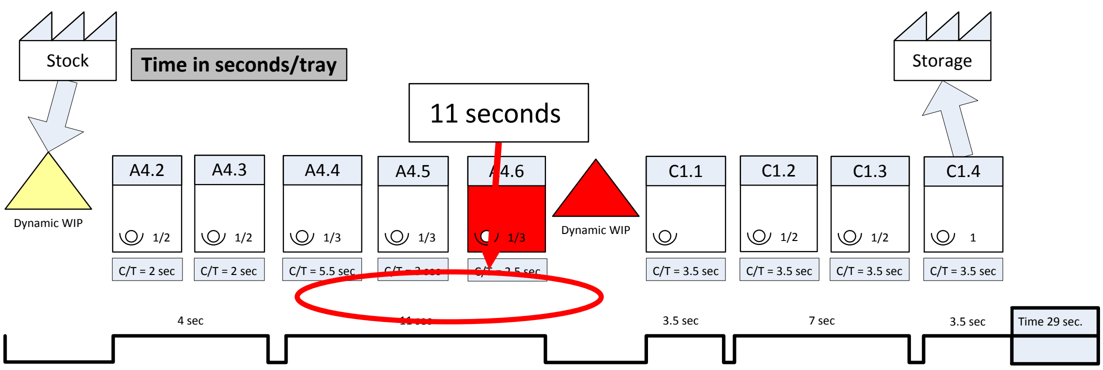


Figure 46. Current state VSM: Process A4 (excluding activity A4.1)

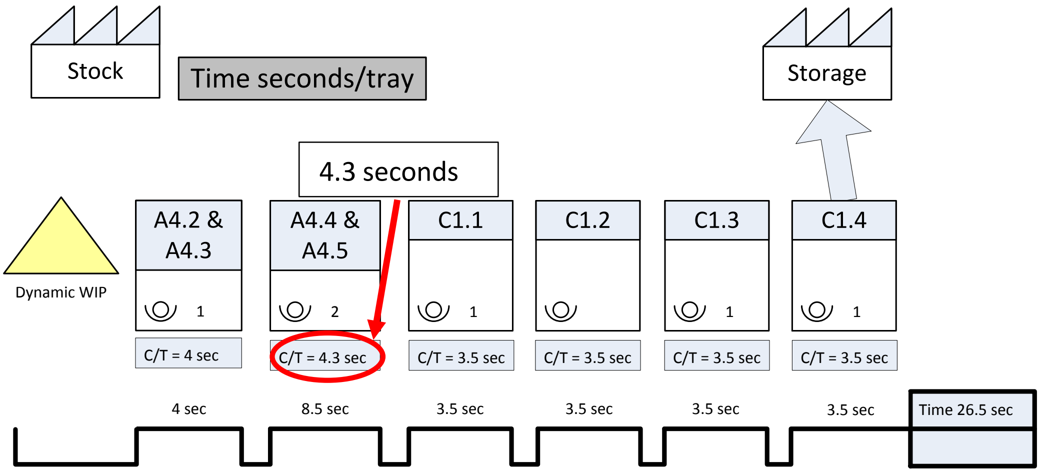


Figure 47. Future state VSM: Process A4 (excluding activity A4.1)

Table 7. Calculation for process A4 processing times for current and future state (excluding activity A4.1).

	Current state (Excluding A4.1)				Future state (Excluding A4.1)		
Volume [Trays]	C/T [sec]	C/T [hrs]	Time [hrs], # Staff (4)		C/T [sec]	C/T [hrs]	Time [hrs], # Staff (8)
0	0	0.00	0.00		0	0.00	0.00
10	110	0.03	0.12		43	0.01	0.07
20	220	0.06	0.24		86	0.02	0.14
30	330	0.09	0.37		129	0.04	0.22
40	440	0.12	0.49		172	0.05	0.29
50	550	0.15	0.61		215	0.06	0.36
60	660	0.18	0.73		258	0.07	0.43
70	770	0.21	0.86		301	0.08	0.50
80	880	0.24	0.98		344	0.10	0.57
90	990	0.28	1.10		387	0.11	0.65
100	1100	0.31	1.22		430	0.12	0.72

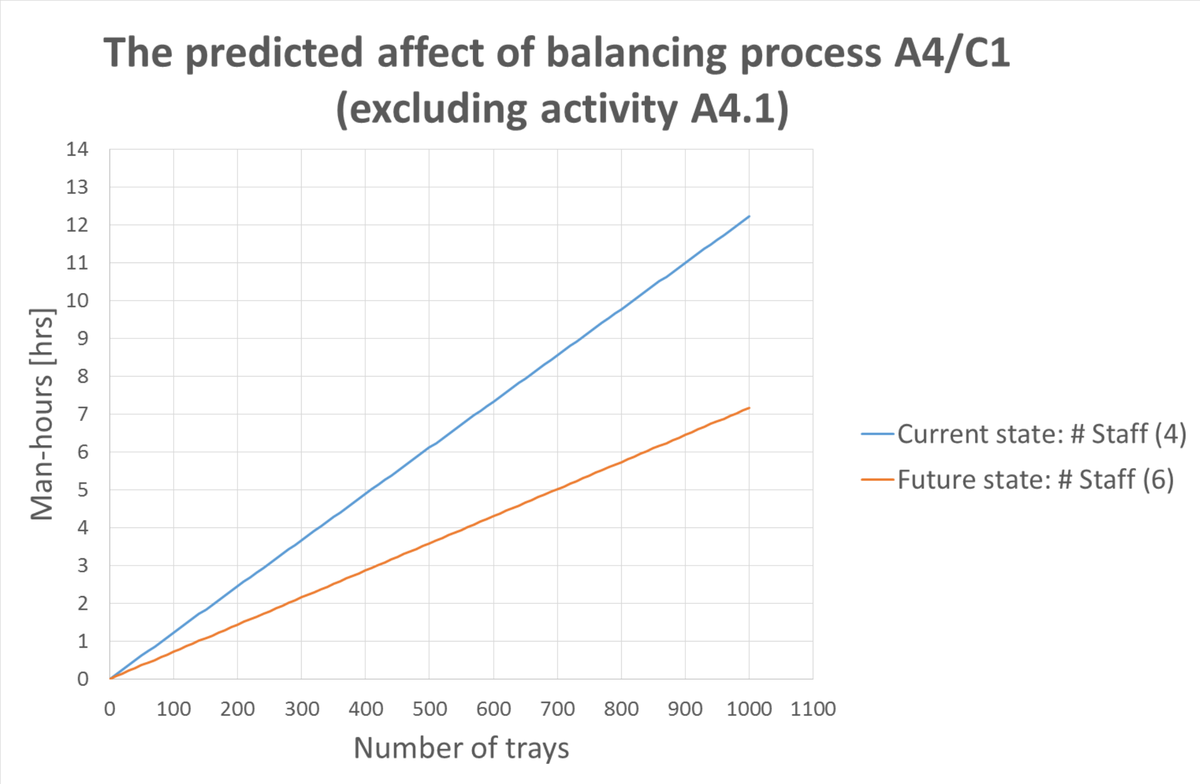


Figure 48. Total amount of man-hours spent per number of trays on process A4 (excluding activity A4.1).

From Figure 48 it can be deduced that the expected outcome of executing the crumbing process as proposed in the future state VSM would result in an approximate 20% reduction in man-hours /per tray.

4.4.3.1 Process C1 feed-in conveyor

In the past the feed-in conveyor for process C1 had been extended (Figure 49). There were two reasons for the extension. Firstly, the extension was added so the weighing and crumbing tables could be left in position at all times. This meant the tables were taking up a significant amount of floor space even when not being used. Secondly, the extension allowed one person to operate process C1; load it, process products, load it up again, etc. etc. This way of working had become unacceptable due to the increase in product volumes. The tray sealer had to be used more efficiently in order to cope with demand.

At this stage in the project the weighing table had already been made obsolete. It had been taken of the floor as part of an intervention during the embedment stage (Figure 14b). Also, the researcher envisioned exploiting the mobility of the process A4 station; place it up against the tray sealer when producing trays (Figure 51a), and place it up against the interdepartmental conveyor when producing bulk (Figure 51b). Considering the purpose of the project — improve process flows, improve equipment utilisation, reduce WIP, and reduce unnecessary movement of stock — the researcher concluded that the conveyor extension was delivering no positive contribution towards reaching set objectives. Other benefits of the reduced length of the conveyor would be the reduced time spent on cleaning, and also the reduced probability of allergen cross contamination occurring. It was decided to bring the process C1 station back to its original configuration.

Figure 49. Process C1 with feeder extension (before)

Figure 50. Process A4 positioned at right angles to the extended conveyor (before).

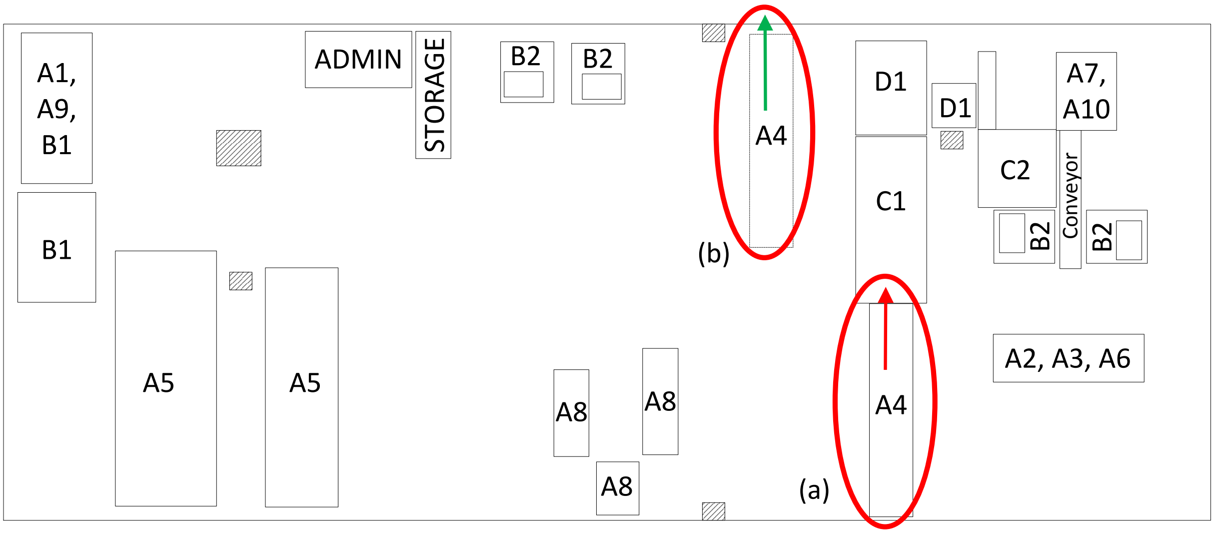


Figure 51. Process C1 feed-in extension has been removed. Placing process A4 up against process C1 when producing trays (a), and placing it up against the interdepartmental conveyor when producing bulk (b).

Figure 52. A simple process (A2/3/6) being executed while feeding straight onto process C1 (after).

In the current state VSM there were 4 staff members starting work early in order to process the required volume of trays. The total volume of trays were put in a buffer awaiting further processing. Once the total volume was put into the buffer the next group of 5 staff members would take over to further process the trays. For this reason the calculation to determine the enchilada line processing times varies from the calculation to determine the crumbing line processing times. Comparing Table

6 and Table 7 with Table 5 shows that for the enchilada line two maximum cycle times were used, 6.8 seconds and 5.3 seconds, whereas for the crumbing line a single maximum cycle time per process was used — 12 seconds and 11 seconds for the process including inserting a bullet and the process excluding inserting a bullet respectively.

4.4.4 Process line A9/B2/C2/D1

Product group 14 is processed on line B2/C2/D1. Hence, all the analysis done above relating to line B2/C2/D1 also applies to product group 14.

4.4.5 Process line A4/D1

Product group 17 is processed on line A4. Hence, all the analysis done above relating to line A4 also applies to product group 7.

4.1 Stage 2 result analysis and interpretation

The approach taken to gain staff's trust, and engage them actively in the change process, resulted in a staged introduction of interventions that were gradually increasing in intrusiveness. The original plant layout (Figure 53) was cluttered and unorganized. Staff was competing for floor space, while equipment was sitting on the shop floor unutilized. Product had to be transported across the plant floor to be further processed: requiring consumables, increasing WIP, and increasing allergen cross contamination risk. As a result, staff was struggling to maintain appropriate levels of allergen control, and more then once failed to pass a quality audit.

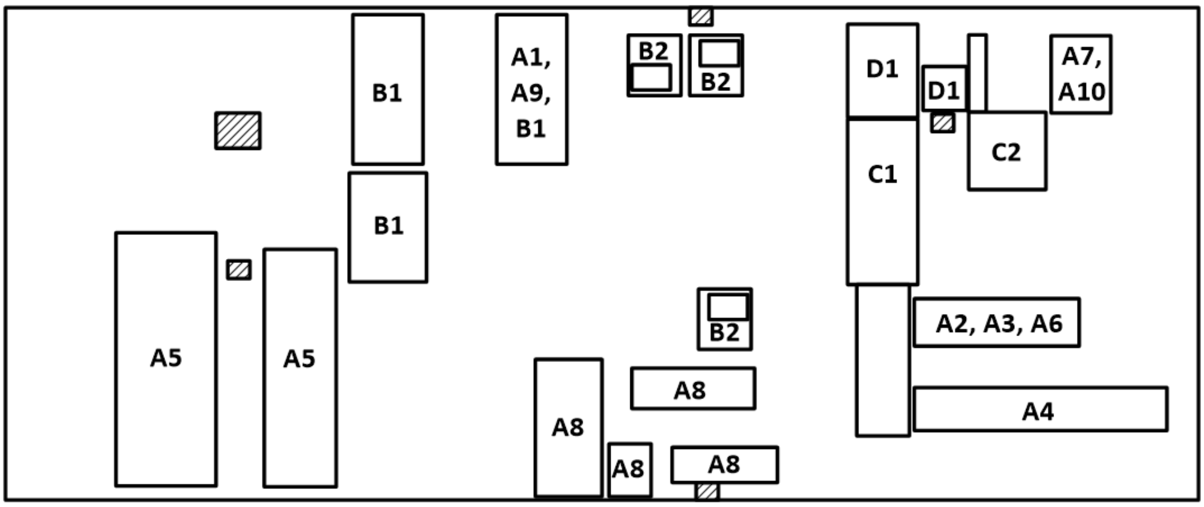


Figure 53. Original layout of the plant.

After completion of stage 2 of the project, utilisation of equipment had increased. The decision to move table A1/A9/B1 to the position shown in Figure 54 resulted in a more organised approach to processing and equipment becoming obsolete. For example, the processes executed on table B1 and table A1/A9/B1 (Figure 53) are now being executed on table A1/A9/B1 only (Figure 54). Other equipment, for example process line A4, is used more effectively by exploiting its mobility, while decreasing allergen cross contamination risk by reducing the movement of stock. The introduction of a conveyor prior to process C2 (Figure 54) saw the complete elimination of required transport in the plant for this particular process. Directly resulting in less WIP and the requirement for consumables. Balancing of process line A8 resulted in the becoming obsolete of yet another piece of equipment, further increasing the available floor space. More generally, the assigning of designated areas to processes and the reduction of movement of stock significantly reduced the risk of allergen cross contamination. Hence, during the quality audit following the improvements a noticeable improvement in term of allergen control was observed. VA staff was commended on having the plant looking clean and tidy, with considerable less spills and effective implemented cleaning strategies.

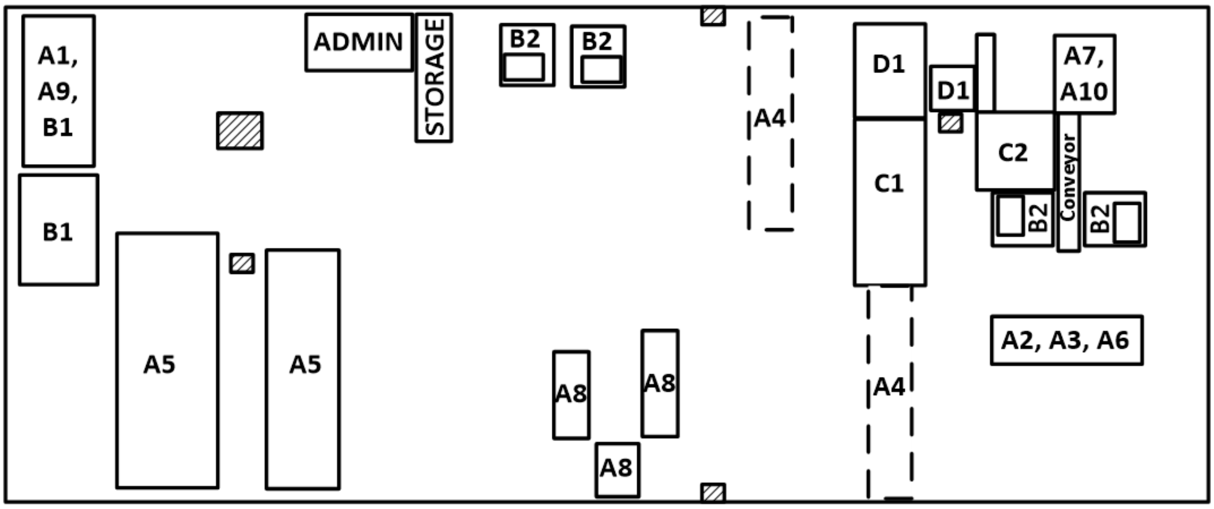


Figure 54. Layout after completion of stage 2.

The plant has a 'Standard' measure for the labour component of the production costs, with 100% being productivity that is marginal, and lower being better. Over 100% and the product is too labor-intensive to give economic returns. The plant's performance data for the period immediately before and after the above interventions are captured in an XmR chart (Figure 55, Figure 56). The XmR chart is actually a set of two charts that are used to measure a quality characteristic for one observation. In this particular case the observation is the accumulated labour cost for the plant for one week. Although not as sensitive as an X-bar and R chart, it will nonetheless allow the user to monitor a process for shifts in the process that alter the mean or variance of the measured statistic. The first chart shows measure 'X' in relation to 'Standard'. Measure 'X' is the accumulated labour cost for the plant for one week. The mR chart, tracks the movement of the range (hence mR) between individual observations. The results show that the plant experienced a drop in mean relative to the Standard, from 69% to 63%. This corresponds to a significant improvement in labour productivity, associated with the above interventions. Furthermore, the variance was significantly reduced, translating in a more predictable plant.

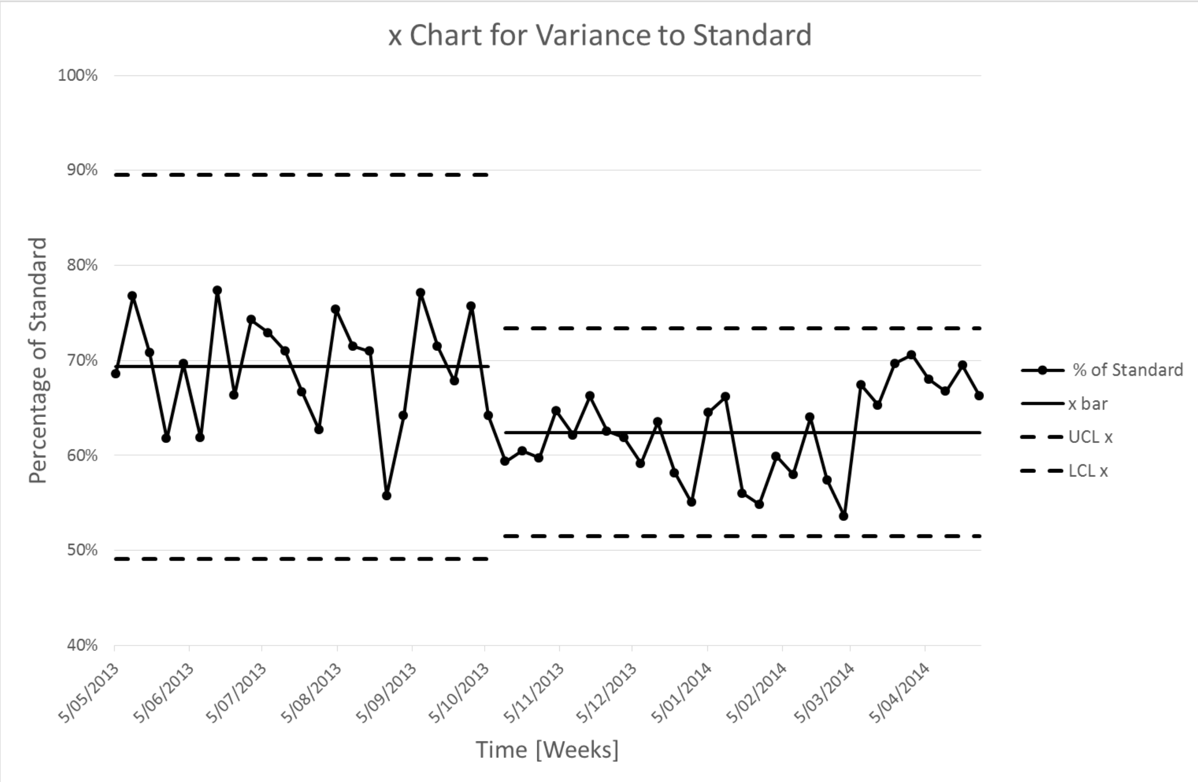


Figure 55. X chart for variance to standard.

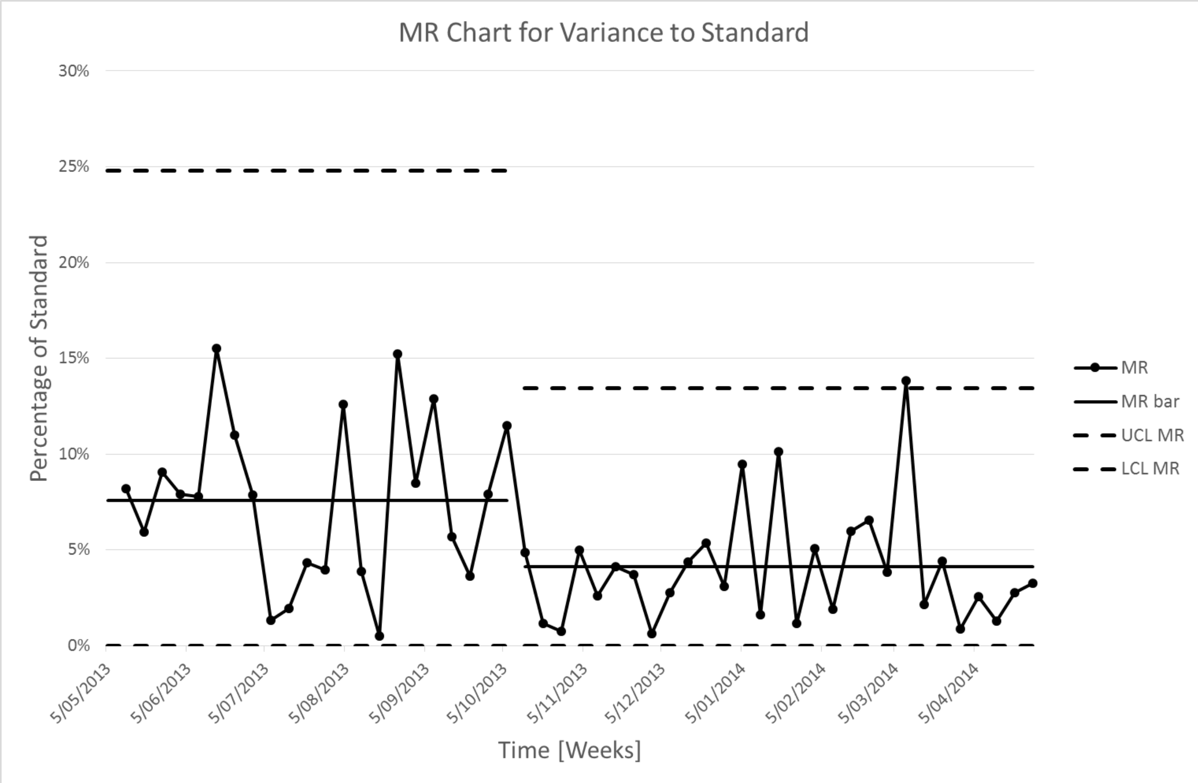


Figure 56. Moving range (mR) chart for variance to standard.

In summary, the interventions introduced during stage 2 of the project resulted in:

- 7% savings on labour cost
- Reduction in plant variability
- Reduced allergen cross contamination risk
- Reduced WIP
- Reduction of consumables
- Increased equipment utilisation

Chapter 5
Stage 3 Results

5.1 Formulation of the problem

The background for the simulation project was the VA plant at Tegel Foods Ltd. The VA plant is a sub-plant of the chicken processing plant. It receives partially processed product from other sub-plants up-stream, adds value to the product by means of additional work, and sends the product downstream to be further processed. Due to an increase in production volumes the company decided to investigate the required changes to be made to the VA plant in order to be able to cope with expected demand.

An area of increasing importance for food manufacturers is allergen control. Allergen contamination can trigger an adverse immune response in the consumer, even leading to fatality. Therefore, the objectives of this simulation project were to optimise plant production flow while also optimising allergen control. That is, to improve process flows, improve equipment utilisation, reduce WIP inventory, and reduce unnecessary movement of stock while also optimising allergen control.

5.2 Testing for simulation-worthiness

The VA plant produced many different products, in ever changing volumes, and on multiple process lines – many of them sharing equipment and machines. Product to be processed at the plant arrived in a stochastic nature, adding to the complexity of the problem. Due to the complexity of the system under investigation, arriving at a solution using numerical analysis was considered to be impractical, if not impossible. Hence, simulation was chosen as the appropriate tool for analysis.

5.3 Formulation of simulation objectives

Throughout the previous stages of the optimization project – embedment and individual process analysis – the author reported on a weekly basis to the plant manager. During these meetings, discussions were held on how the company was measuring targets. Processes were not measured separately, but rather, the efficiency of the processes was measured as a cumulative weekly labour cost. To keep in line with company practise, the main performance measure was chosen to be labour cost, with staff and machine utilisation selected as additional performance measures. For this reason, the questions posed to be answered by executing a discrete event simulation were:

1. What are the effects on labour cost when implementing temporal separation between products by ways of random product mix and fixed-time cleaning schedule?
2. What are the effects on labour cost when implementing temporal separation between products by ways of scheduled product mix and variable-time cleaning schedule?
3. What are the effects on labour cost when implementing spatial separation between products by ways of running 2 identical packaging lines: one for plain product, one for product containing allergens?
4. What are the effects on labour cost when optimising plant layout based on consumables used on the process lines (trays, film, labels, and bags) and process line proximity to the storeroom?

5.4 Data collection and data analysis

Data for the simulation study was collected throughout the project during stage 1: embedment of researcher, stage 2: individual process analysis, and stage 3: plant wide analysis. What follows is an explanation about the sources, necessary adjustments, and assumptions made for each data type.

5.4.1 Production forecast information

The production forecast information is used to plan, among other things, production requirements. Requirements for the plant under investigation were obtained by the author via interview with management. Based on the quality of the forecast data available it was decided that historical data relating to product volumes was to be used. This data was made available to the author by the production analysis office as a spreadsheet.

5.4.2 Process and setup times

This type of date was not being logged by the company: no historical data existed for process and setup times. Process times used in this simulation are estimations made by the author based on calculations from observations. Data were collected for each process in the VA plant. Sample size was at least five observations per sample in order to be able to capture normal behaviour of the process. Setup times were estimates based on observations made by the VA plant team leaders in conjunction with the author.

5.4.3 Maintenance information

This type of data was not logged by the company. Maintenance was limited to break-down maintenance, and no records were kept on duration and frequency of break-downs. Estimates for percentage of machine availability for production, and MTTR were made based on observations made by the author.

5.4.4 Quality and compliance information

Product arrived at the VA plant in volumes in excess of demand. Product that failed the quality check was reworked immediately in case it was recoverable, otherwise discarded. Data for rejected units were not recorded.

Allergen control information was obtained from the quality control and compliance office. Data relating product, ingredients, and allergen for the whole processing plant was presented to the author in a spread sheet. The data was ordered such that it lists the products from least to most allergen content. That is, a product containing no allergen starts the list, followed by a product containing one allergen, and so on. This list then, in effect, became a production sequence for implementing allergen control. Moreover, the list gave insight into what sort of cleaning was required between change-overs; whether the change-over required, either major setups, or minor setups. Where a major setup is different from a minor setup by way of time taken to execute.

5.4.5 Process information

Process information was obtained from management, team leaders, and operators. Information was obtained through interview, and direct observation. With the author working alongside operators and team leaders, the interviews conducted took on an open-ended nature. The respondent's opinions and insights into the processes under investigation served as a basis for further inquiry.

Direct observation was used as a means to obtain confirmation of statements made in interviews, or as a means to instigate discussion with operators and team leaders.

5.4.6 Plant description

Taking into consideration the results from the collected data obtained from interviews, meetings, and direct observation, it was possible to build up a characterisation of the VA Plant.

5.4.6.1 Product characterization

The data for the products produced in the VA plant were provided by the production analysis office and came in the form of a spread sheet. This data was used as an input for the simulation model. The file contained the date of production, the product description, production volumes, production weights, and whether it was individually packed or send out in bulk (Figure 57).

A	B	C	D	E	F	G
CATEORY 2	Appetit Crumb					
			Traypack	Values		
			TP		Bulk	
Date	Product Description	Act Output	Sum of Output Outers	Sum of Total Trays	Sum of Output Outers	Sum of Total Trays
22-04-14	FS CORDON BLEU CBD B/FLT BULK	17.15			7	0
	FS CRMY PESTO CBD BFLT APPETIT	10.5			4	0
	FS GARLIC BUTTER KIEV APPETITE	10.1			4	0
	FS ITALIAN CBD B/FLT TP	10.5	4	24		
	FS S/D TOM&FETA CBD BFLT APPET	0			0	0
	FS TP CORDON BLEU CBD B/FLT	77.75	30	180		
	FS TP CRMY PESTO CBD B/FLT	39.6	16	96		
	FS TP GARLIC BUTTER KIEV	93	39	234		
	FS TP HNY MUSTARD CBD B/FLT	12.55	5	30		
	FS TP S/D TOM&FETA CBD B/FLT	32.05	13	78		
22-04-14 Total			107	642	15	0
Grand Total			107	642	15	0

Figure 57. Historical production data for a typical VA plant product. Note the product diversity is augmented by taking the generic quality of the product by adding the additional quality of flavour.

5.4.6.2 VA plant processes characterization

From work done earlier in the project the process flows in the VA plant were known. Required sequences had been established, and processing times for individual tasks were obtained. Scheduling heuristics as well as observed routines to assure cleanliness and allergen control were obtained from interviews with team leaders and operators.

Data for the amount of hours worked per person per day was obtained from the human resources (HR) department. Employees swipe in prior to commencing work, and swipe out after work is completed. Also, they swipe in and out when going for lunch. The data is collected in a system called ADI. Access to the system was granted to the author by HR.

5.4.6.3 Machine and equipment characterization

Each product has specific process and setup times associated with it depending on machine and equipment used. Equipment were predominantly tables and transport bins. In order to maintain cleanliness and implement allergen control, tables were covered with a plastic sheet prior to production. Sheet was removed, discarded, and replaced every time a different product was to be processed. Transport bins were washed every time between product change-over.

A distinction could be made between machines that were used in a product specific process, and those that were shared between processes. Product specific machinery – executing only one particular operation on one particular product – was cleaned ones a day at the end of the day's production. Machines that were shared between processes were cleaned following visual cues. That is, machines were cleaned when a significant amount of residue was observed on the machines surfaces. Notably, machines were not cleaned considering allergen cross contamination risk. When it was cleaned, no consideration was given to whether the next product to be produced could be contaminated by the previous product or not: the machine was always cleaned to the highest level of cleanliness possible. To put it in context: to maintain the highest level of cleanliness when changing over between products that contain the same allergens is a waste of resources.

5.5 Modelling

5.5.1 Assumptions

The development of a discrete event simulation model requires a simplification of the system under investigation. These simplifications translate into assumptions and these are listed below.

- Monday's production volumes and product mix are representative for average daily production volumes and product mix throughout the week.
- No less than 16, and no more than 18 staff are available for processing.
- Work starts at 6:00 am for 4 employees with the remainder starting at 7:30 am.
- A linear relationship exists between production time and production volume.
- Work is considered finished when all required products have been processed. End of day clean-up and preparatory work for next day's production are not being modelled.
- Setup times are assumed to be deterministic.
- Process times are normally distributed.
- Product arrival times follow a log-normal distribution. This assumption is based on the observation of product arriving usually within a narrow time frame, but occasionally much later. A distribution with a long tail was required.
- The number of individually packed products to be processed is evenly divisible by the number of boxes required for their transportation.
- The number of products required to be tumbled (process A5) is rounded to the nearest integer evenly divisible by 1500.
- Products added to the product mix after 20/04/14 have not been included in the model.

5.5.2 Model translation

The specific simulation tool used for plant-wide analysis was Siemens Tecnomatix Plant Simulation 11[2]. Tecnomatix is a product that is part of the Product Lifecycle Management (PLM) software package developed by Siemens. The first step taken was to model each individual process in a separate frame. Using process A8 Skewering/Cutting as an example, the procedure on how a frame was build will be explained.

1. The spatial layout of the process was determined and activities making up the process were identified (Figure 58).
2. Activities were translated into a model while being mindful the model layout resembled the spatial layout as much as possible. Buffers and sources for consumables were added to obtain functionality (Figure 59).
3. Appropriate settings were selected for each activity. Each activity is represented by an icon. Each icon 'opens up' into a myriad of choices to fine tune the behaviour of the activity (Figure 60). The main parameters of interest being: processing time, set-up time, start time, priority, observer selection, predecessor and successor selection, failures, and assembly table.
4. Specific tasks were assigned to specific operators (Figure 61).
5. Coding was required to add further functionality to the model. In Tecnomatix this requires the use of 'Methods' (The two icons in the top left corner in Figure 59 and Figure 61). Methods allow for the adding of complexity to a model not obtainable via the use of standard icons and settings only. Examples of this are:
    a. The selection of the number of jigs and guides present in the process at start-up (Figure 62),
    b. The time the process will become active relevant to other modelled VA plant processes (Figure 63).

[2] http://www.plm.automation.siemens.com/en_us/products/tecnomatix/

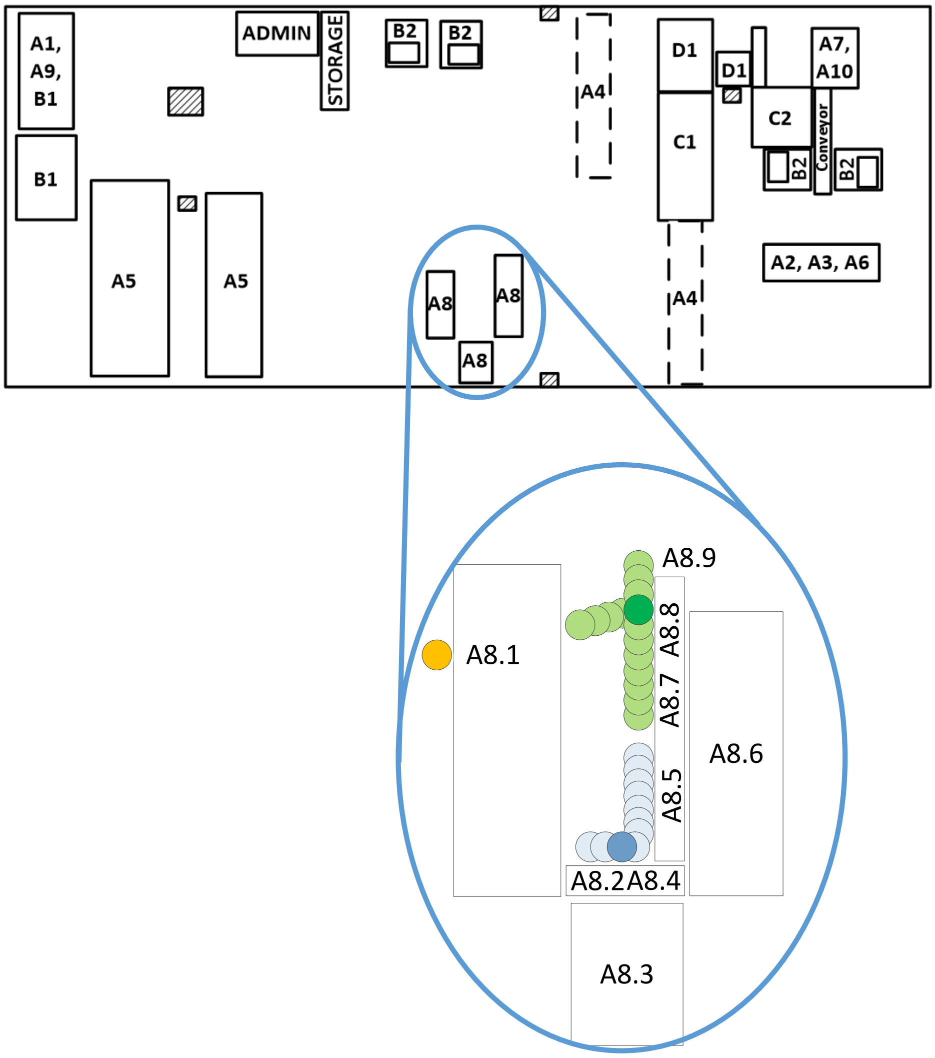


Figure 58. Spatial layout for process A8. The top diagram represents the VA plant layout, while the insert represents process A8 in more detail. In the detail the activities A8.1 to A8.9 are shown in there approximate position and sequence as they appear in the process. Also shown in the detail is the movement of staff while executing the process.

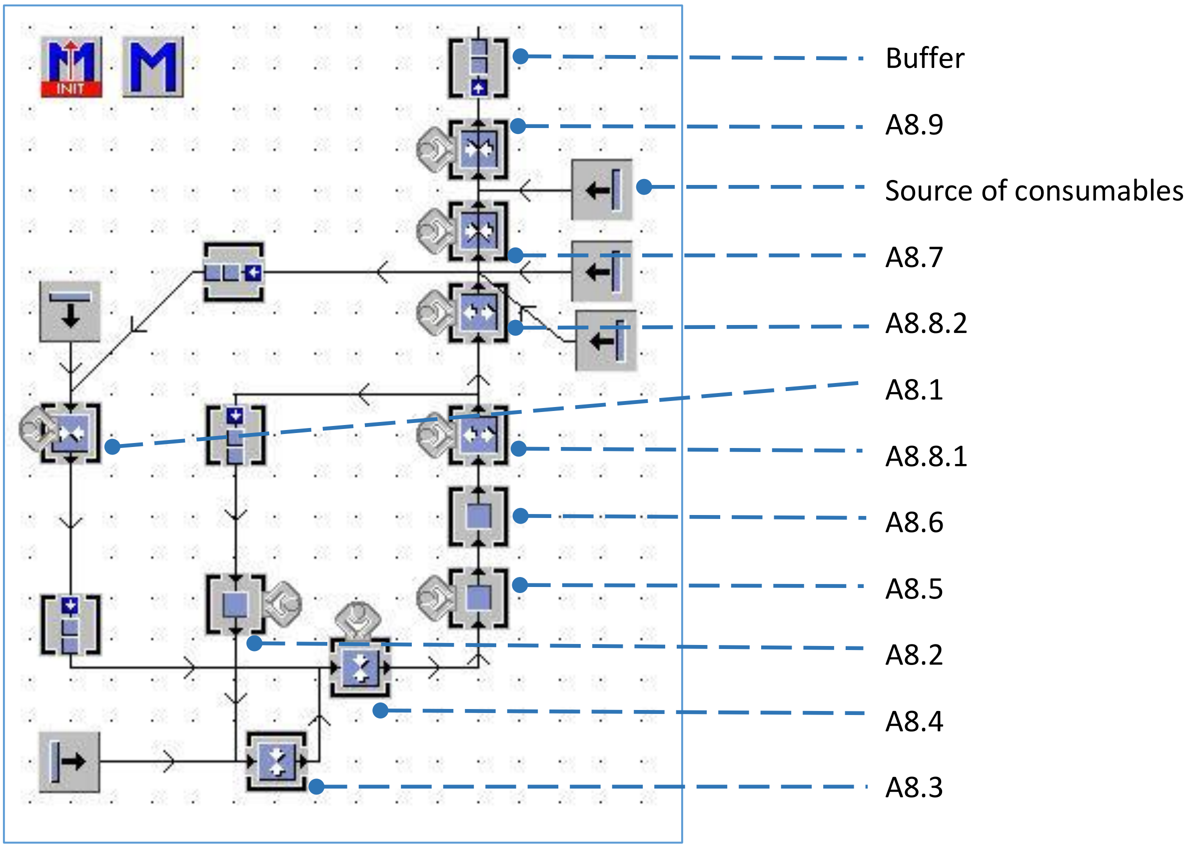


Figure 59. Translated model of process A8. The process starts with activity A8.1 where the operator recieves a jig from a buffer and product from a source. The loaded jig is placed in a buffer. The jig is received by the next operator who loads up the jig with a guide, and loads and unloads the cutting machine, executing activies A8.2 to A8.8.1 respectively. The guide is placed in a buffer, and the jig containing the cut product is handed over to the next operator. The process is followed through until the final activity A8.9 of disassembling the jig is executed and the processed product is placed in a buffer. The jig is placed in a buffer and the process repeats.

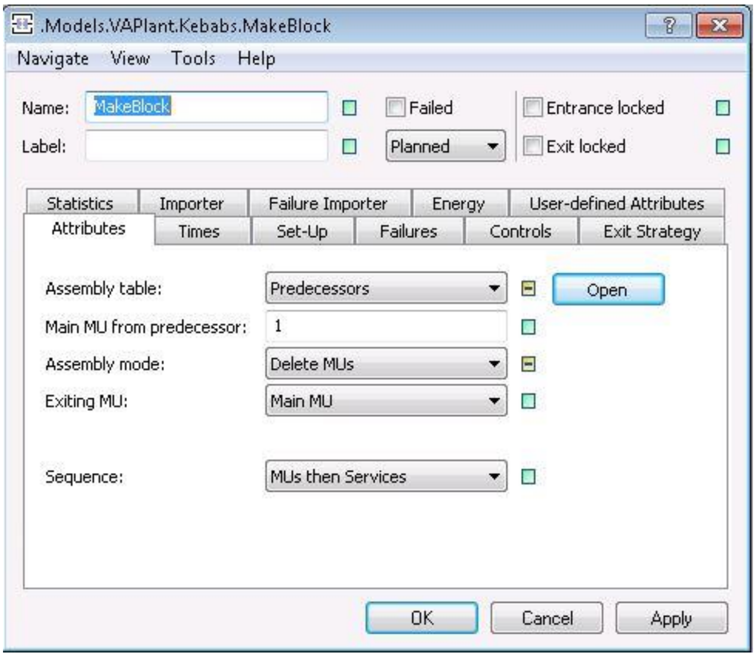


Figure 60. Process 8: A myriad of choices for each icon repesenting an activity. The choices allow for fine tunning the behavior of the activity.

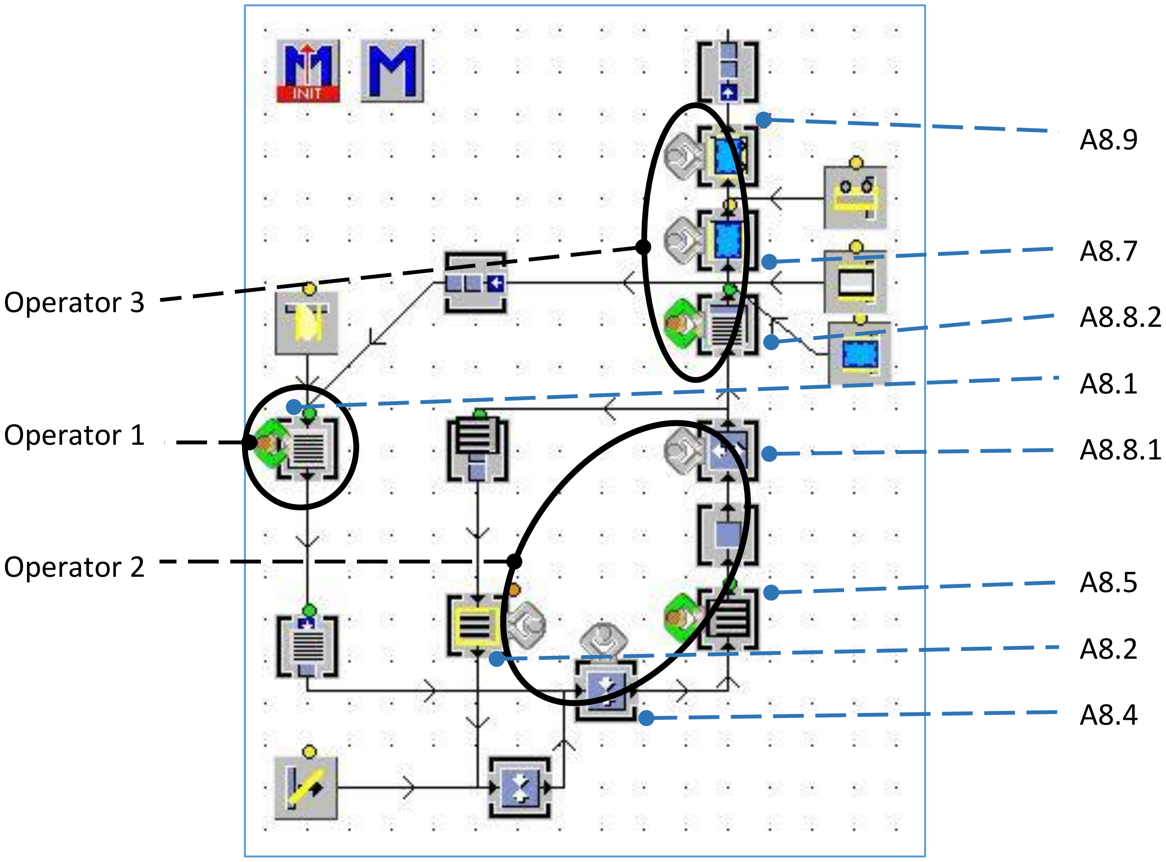


Figure 61. Process A8: Specific tasks assigned to specific operators. Analysis of process A8 in phase two of the project revealed what task to assign to which operator. Hence, operator 1 is assigned to task A8.1; operator two is assigned to task A8.2, A8.4, A8.5, and A8.8.1; and operator 3 is assigned to task A8.7, A8.8.2, and A8.9.

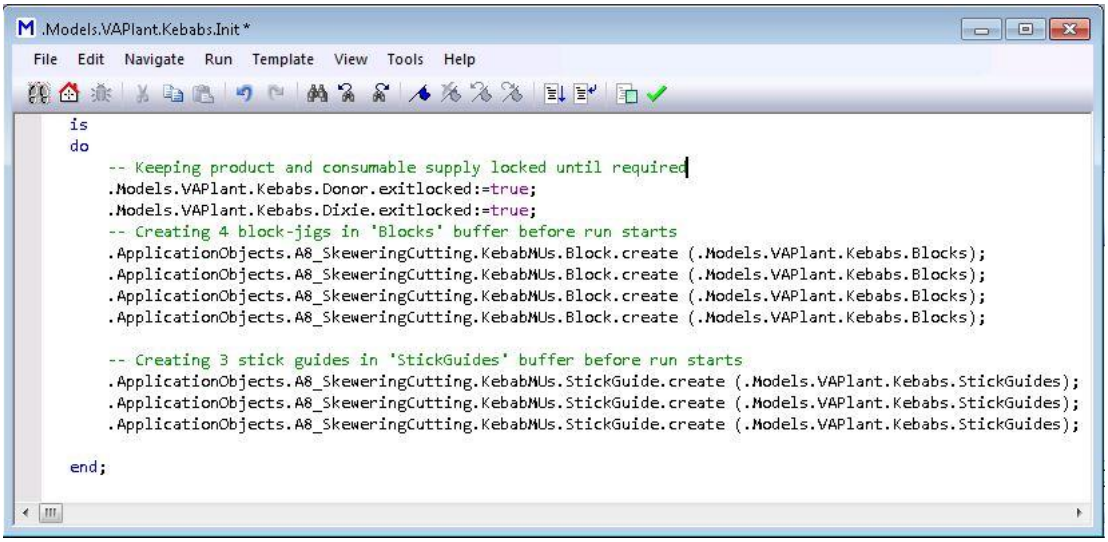


Figure 62. Method containing code to model number of jigs and guides in the frame. On start up of the simulation the jigs and guides appear in the buffer. Much like the way operators would find them on commencement of the work day.

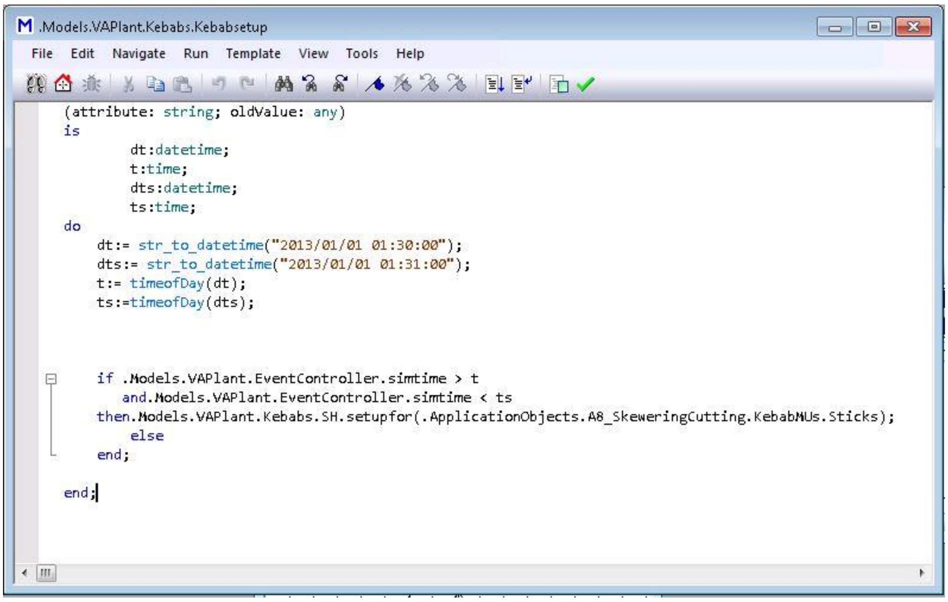


Figure 63. Method containing code to model the activation of the process based on a predetermined time. Process A8 is allowed to start processing at 1:30:00 simulation time. The time the process actualy starts depends also on product arrival time and operator availability, but the process can start no sooner than 1:30:00 simulation time.

After having completed the above mentioned steps for all the processes, the frames were linked together and combined in the VA plant frame. To add further functionality to the VA plant frame, product mix selection tables, and setup tables were added (Figure 64). Linking the frames together means that the processes can run simultaneously if so required. Also, it means that processes can run in a preferred sequence if so required.

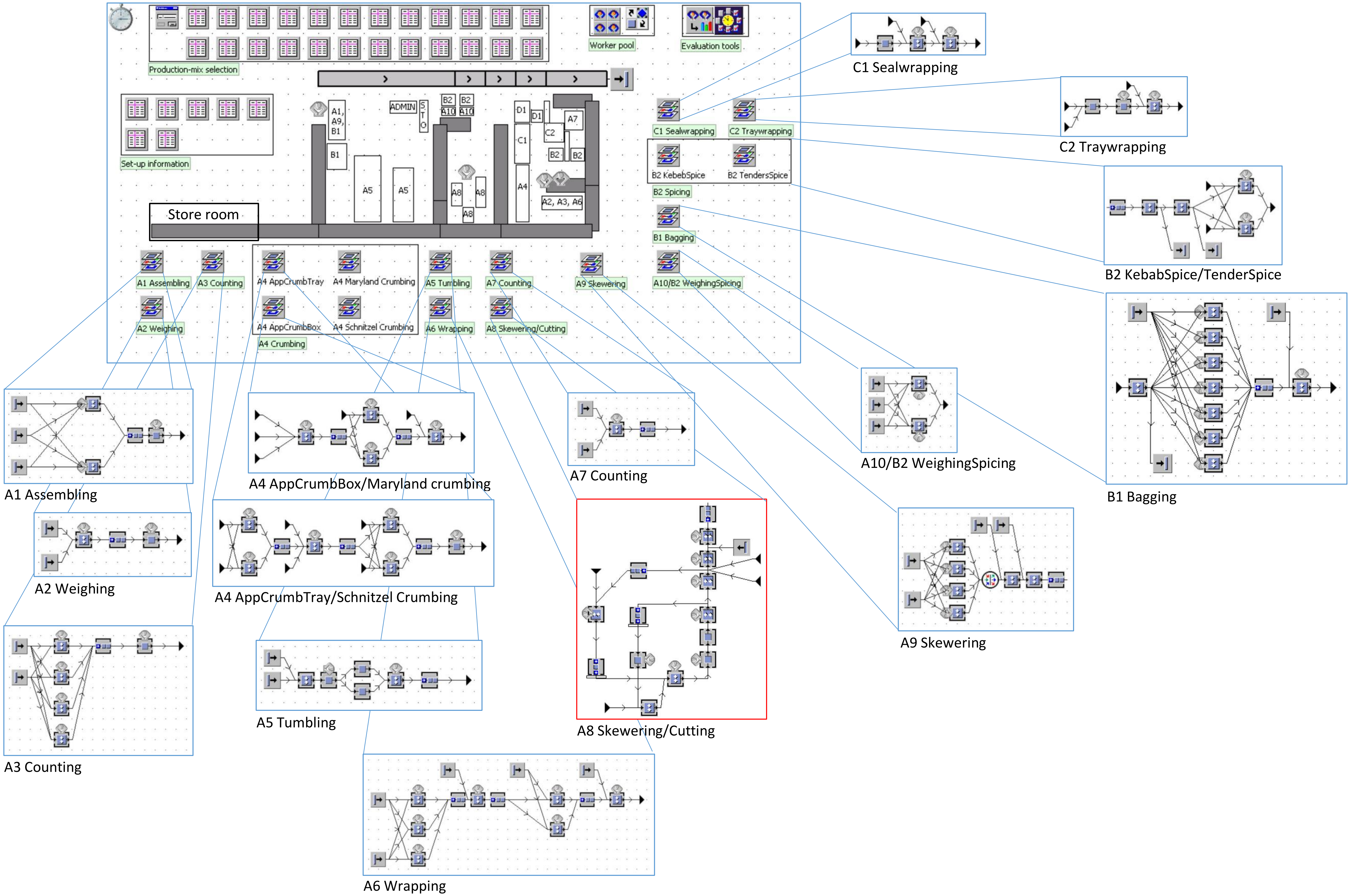


Figure 64. Translated VA plant model

5.5.3 Model verification

Verification of the simulation model occurred synchronously while the model was gradually translated in its entirety into software. Verification consisted of the debugging of code and confirming accurate behaviour of items progressing through the simulated processes. The simulation was ran event by event to check for undesired behaviour. In the case of inconsistencies occurring in the code: the code was modified. In the case of inaccurate behaviour of items through the simulated process: the activity settings were checked and adjusted. Eventually a simulation model was build in software. The required features of the model, as determined in the data collection and analysis stage described above, were eventually displayed by the model. These were:

- Multiple sequential processing lines operating in parallel.
- Job selection based on allocated priority.
- Dynamic allocation of labour units.
- Selection of setup time based on product.
- Stochastic behaviour

The date range of 13-10-13 to 27-04-14 was selected to provide the production data required for simulation. The range represents the period for which the processes modified in stage 2 were monitored. The range of dates captured the seasonality in demand: the months November, December, and January are those of high demand, with demand dropping significantly immediately after. In order to reduce the size of the data set to more manageable proportions the following assumption was made: Monday's production volumes and product mix are representative for average daily production volumes and product mix throughout the week. Furthermore, in order to reduce complexity in the simulation model, only those Mondays were selected that had no less than 16, and no more than 18 labour units available on that particular day of processing. Whereas the total data set consisted of n=27 Mondays available to provide production data, applying the constraints reduced the data set to n=13 Mondays available to provide production data (Table 8).

Since the simulation model displays stochastic behaviour, the number of observations per experiment to reach steady state had to be determined. From the 13 data sets available, one set was randomly selected to determine the steady state of the simulation model. The number of observations per experiment was set to a 5 and the simulation was run. After having collected the data the number of observations per experiment was set to 10, and again the simulation was run and the data collected. This process was repeated with intervals of 10 observations until the simulation was run with 160 observations per experiment. The collected data for each experiment was plotted, and from the plot it was deduced that steady state for the current state model occurred at 140 observations per experiment (Figure 65). This meant that, in order to obtain accurate results, for every single experiment, that is, for every selected Monday contributing production data, 140 observations had to be made.

Table 8. Selection of Mondays used to provide production volume and product mix data for simulation.

#	Date
1	18-11-13
2	25-11-13
3	02-12-13
4	20-01-14
5	27-01-14
6	03-02-14
7	17-02-14
8	03-03-14
9	10-03-14
10	24-03-14
11	31-03-14
12	07-04-14
13	14-04-14

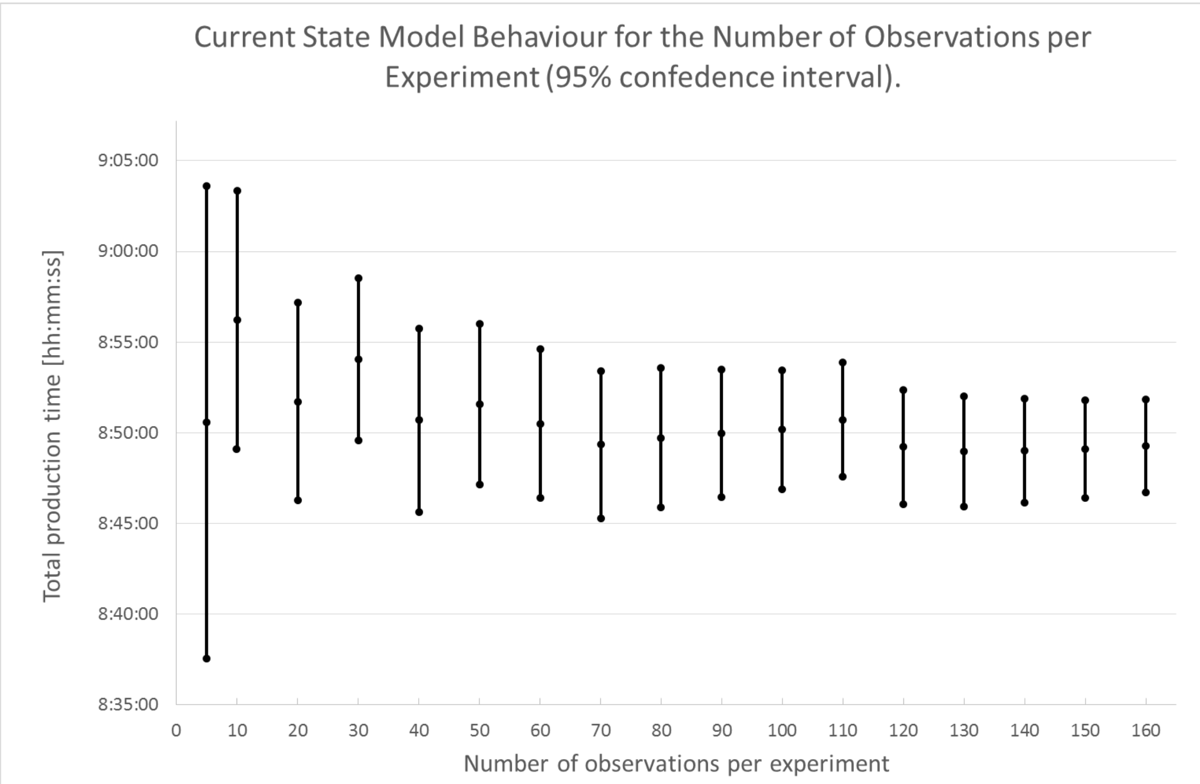


Figure 65. Steady state of the model is observed at 140 observation per experiment.

Early on in the project a choice was made to simplify analysis by ways of reducing the amount of products handled by the VA plant processes. It was decided to analyse only those products that added more than 1% of total production cost to the overall cost.

To make to results of the simulation runs meaningful the results from the simulation runs were scaled in order to take into account the reduced processed volume caused by not modelling the products adding less then 1% of total production cost. The date Monday 03-02-14 was selected to determine the difference in production volumes (Table 9). From the table we find:

- Total actual production volume [TAPV] = 7788 kg
- Total simulation production volume [TSPV] = 6750 kg

While TAPV and TSPV are different for every date one selects, the resulting ratio was assumed to be approximatly equal for any given day of production.

From Table 10 we find that the Actual production time [APT] = Total production time – (Tea breaks + Lunch break) = 10:15:00 – (0:20:00 + 0:30:00) = 9:25:00 hrs.

The adjusted actual production produciton time can then be calculated as follows:

$$Adjusted\ actual\ production\ time = \frac{TSPV}{TAPV} \times APT = \frac{6750\ kg}{7788\ kg} \times 9{:}25{:}00\ hrs \approx 8{:}12{:}00\ hrs$$

Or, more general, the Adjusted Actual Production Time is approximately 87% of Actual Production Time.

Since the APT was available for the whole data set, and the scaling factor had been determined, we were in a position to calculate AAPT for all data sets. The results are presented in Figure 66 and show that scaling APT does bring down total production time, but has no significant impact on variability.

Table 9. Selection of production volumes to be included in the simulation model for Monday 03-02-14.

Date	Product Code	Actual Production Volume [kg]	Simulated Y/N	Simulated Production Volume [kg]
03-02-14	460229	53	Y	53
03-02-14	730339	323	Y	323
03-02-14	651856	18	N	
03-02-14	460663	23	Y	23
03-02-14	653430	49	N	
03-02-14	460670	23	Y	23
03-02-14	461202	58	Y	58
03-02-14	750160	35	Y	35
03-02-14	461301	18	Y	18
03-02-14	460915	93	Y	93
03-02-14	460038	109	Y	109
03-02-14	681648	24	Y	24
03-02-14	681549	19	Y	19
03-02-14	682805	19	Y	19
03-02-14	651122	21	N	
03-02-14	461011	65	Y	65
03-02-14	460939	64	Y	64
03-02-14	682690	51	N	
03-02-14	683086	43	Y	43
03-02-14	461622	34	Y	34
03-02-14	461110	32	Y	32
03-02-14	682898	34	N	
03-02-14	682591	84	N	
03-02-14	682799	49	N	
03-02-14	682546	42	Y	42
03-02-14	680061	47	Y	47
03-02-14	682553	96	Y	96
03-02-14	681501	332	Y	332
03-02-14	681709	48	Y	48
03-02-14	682584	105	Y	105
03-02-14	681402	194	Y	194
03-02-14	460694	0	Y	0
03-02-14	750306	63	Y	63
03-02-14	461721	24	Y	24
03-02-14	461035	28	Y	28
03-02-14	461127	15	Y	15
03-02-14	461424	36	Y	36
03-02-14	461219	141	Y	141
03-02-14	461233	21	Y	21
03-02-14	461226	2	Y	2
03-02-14	682904	19	Y	19
03-02-14	461738	30	Y	30
03-02-14	230969	0	Y	0
03-02-14	230860	0	Y	0
03-02-14	460656	7	Y	7
03-02-14	630127	3	N	
03-02-14	638307	39	Y	39
03-02-14	638321	187	N	
03-02-14	651108	40	Y	40
03-02-14	651719	78	N	
03-02-14	651955	21	Y	21
03-02-14	655441	5	N	
03-02-14	661510	0	N	
03-02-14	661534	4	N	
03-02-14	730063	382	Y	382
03-02-14	730094	30	N	
03-02-14	730292	30	N	
03-02-14	730391	30	N	
03-02-14	733736	1731	Y	1731
03-02-14	734009	716	Y	716
03-02-14	734504	229	Y	229
03-02-14	750368	281	Y	281
03-02-14	750375	41	Y	41
03-02-14	750443	382	Y	382
03-02-14	750726	54	Y	54
03-02-14	750832	437	Y	437
03-02-14	830060	38	N	
03-02-14	850358	15	N	
03-02-14	661336	4	N	
03-02-14	661411	8	N	
03-02-14	750351	30	N	
03-02-14	850570	0	N	
03-02-14	661312	4	N	
03-02-14	461318	12	Y	12
03-02-14	635627	9	N	
03-02-14	650583	7	N	
03-02-14	650682	15	Y	15
03-02-14	635528	41	N	
03-02-14	650781	88	Y	88
03-02-14	651184	35	N	
03-02-14	579648	41	N	
03-02-14	579549	41	N	
03-02-14	639038	14	N	
03-02-14	639137	13	N	
03-02-14	653331	51	N	
03-02-14	653539	12	N	
	TOTAL	7788		6750

Table 10. Times worked by individual operators for Monday 03-02-14

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:30	13:00			Staff count	19
Operator 1	13:30	16:15	8:15		Away	1
Operator 2	7:32	12:38			Working	18
Operator 2	13:10	16:17	8:13			
Operator 3	7:26	12:45			Max time	16:15:00
Operator 3	13:16	16:16	8:19		Start time	6:00:00
Operator 4	7:30	12:30			Tot Prod Time	10:15:00
Operator 4	13:00	16:15	8:15			
Operator 5					Tea breaks	0:20:00
Operator 6	7:37	12:38			Lunch break	0:30:00
Operator 6	13:15	16:13	7:59			
Operator 7	7:37	12:38			Sum_hrs	149:21:00
Operator 7	13:15	16:13	7:59			
Operator 8	6:49	12:31			Avg_hrs/LabourUnit	7:57:50
Operator 8	13:03	15:59	8:38			
Operator 9	7:30	16:00	8:30		Production Volume	7788
Operator 10	5:57	12:50				
Operator 10	13:21	15:16	8:48			
Operator 11	5:57	12:44				
Operator 11	13:14	15:57	9:30			
Operator 12	7:22	12:53				
Operator 12	13:18	16:09	8:22			
Operator 13	7:25	12:44				
Operator 13	13:14	16:12	8:17			
Operator 14	9:03	12:42				
Operator 14	13:16	14:26	4:49			
Operator 15	7:29	12:37				
Operator 15	13:12	16:12	8:08			
Operator 16	5:56	12:42				
Operator 16	13:12	15:55	9:29			
Operator 17	7:34	12:45				
Operator 17	13:16	17:40	9:35			
Operator 18	7:27	12:44				
Operator 18	13:15	16:09	8:11			
Operator 19	3:50	6:22				
Operator 19	8:48	14:20	8:04			

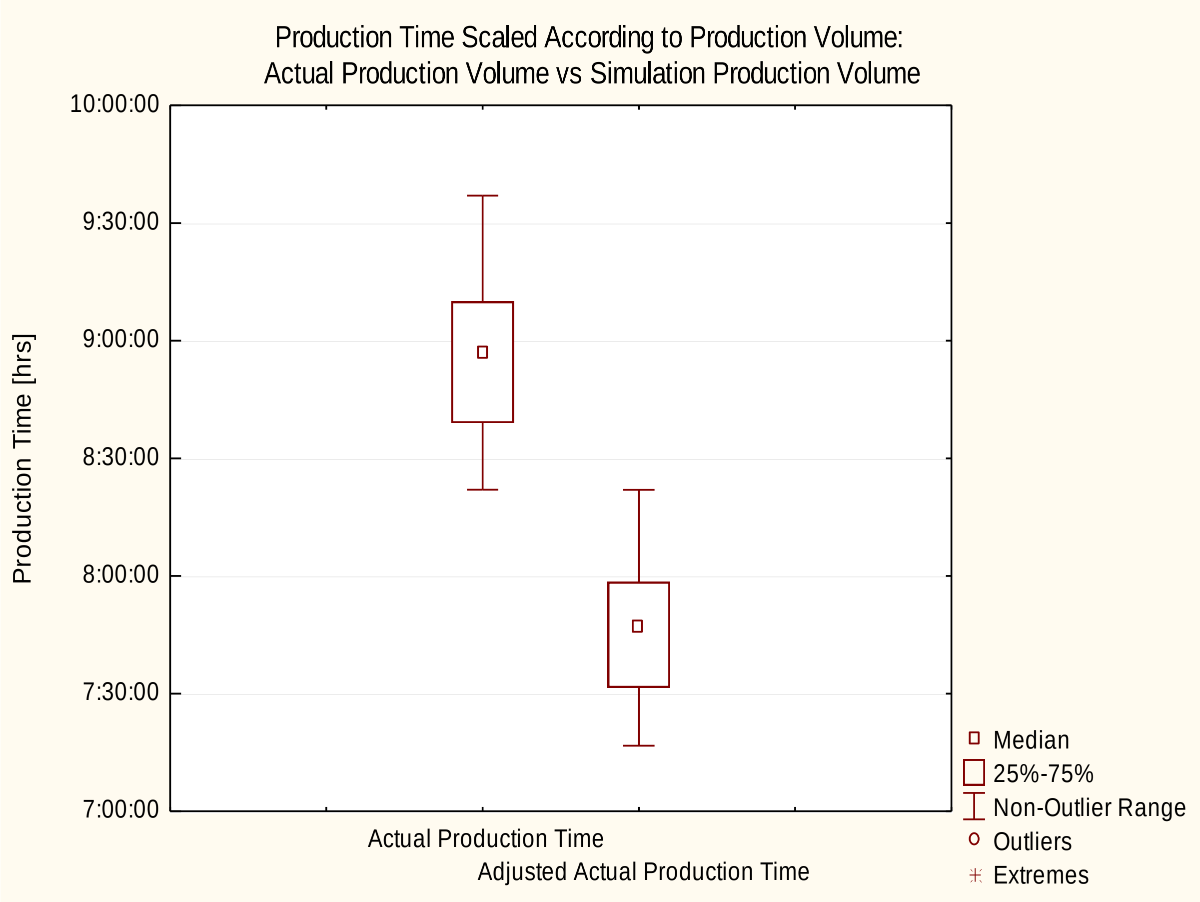


Figure 66. Restults for applying a scaling factor to actual production time to account for reduced processed volumes in the simulation model.

5.5.1 Model calibration

The next step was to calibrate the simulation production time (SPT) against AAPT. A total of 13 Mondays had been selected to provide production data to be used in the simulations. The 13 Mondays provided 13 sets of production volumes and product mixes which were each entered in the production mix table in the translated VA plant model. The simulation model was run 13 times: once for every selected Monday. Remember, every single simulation required 140 observation in order to obtain maximum accuracy. The resulting data – 13 x 140 SPTs – were collected and plotted. The results are presented in Figure 67.

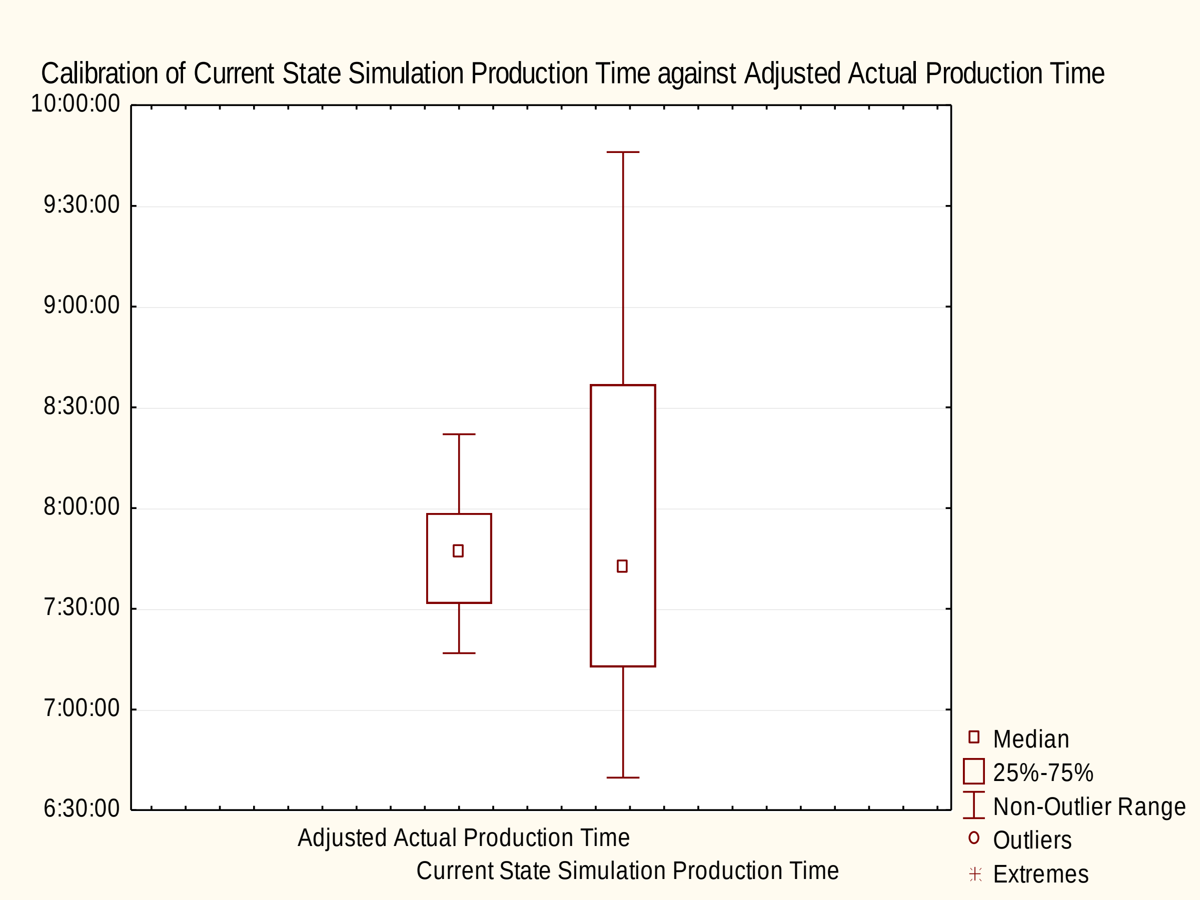


Figure 67. Observed increased variability for Current State SPTcompared to AAPT

The results show that due to scaling the AAPT, the median of the current state SPT is close to the median of the AAPT. It went not unnoticed though, that the variability in the production time predicted by the simulation model did not compare well to the variability observed in the AAPT. Having assured earlier on that the scaling factor did not significantly alter the variability of the AAPT compared to the APT, an answer had to be found for what was causing the increase in variability for current state SPT.

A possible answer for increased variability for current state SPT was found when comparing average production rates per person in relation to production volume. From the ADI system the time worked by each operator per day was obtained and placed in a spreadsheet. From this the average time worked by the operators was calculated (Table 10). From the historical production data, the production volume was obtained. For a full set of operator data see Appendix A. Data were combined and organised as shown in Table 11. Plotting the data reveals a strong linear relationship (R^2 = 0.8618) between required daily production volume and average production rate per person (Figure 68).

Table 11. Production data for selected Mondays for the period 13-10-13 to 27-03-14.

#	Date	Production Volume [kg]	Avg_hrs/LabourUnit	Avg_Seconds/LabourUnit	Avg. Production Rate [sec/kg]
1	03-02-14	7788	7:55:57	28557	3.67
2	14-04-14	6905	7:41:30	27690	4.01
3	10-03-14	6746	7:40:06	27606	4.09
4	20-01-14	6028	7:26:49	26809	4.45
5	24-03-14	5842	7:21:20	26480	4.53
6	27-01-14	5450	6:59:34	25174	4.62
7	03-03-14	5806	7:22:47	26567	4.58
8	17-02-14	5894	8:04:56	29096	4.94
9	07-04-14	5336	7:21:03	26463	4.96
10	18-11-13	6130	8:26:56	30416	4.96
11	31-03-14	4829	7:09:07	25747	5.33
12	02-12-13	4562	7:04:28	25468	5.58
13	25-11-13	4652	7:36:36	27396	5.89

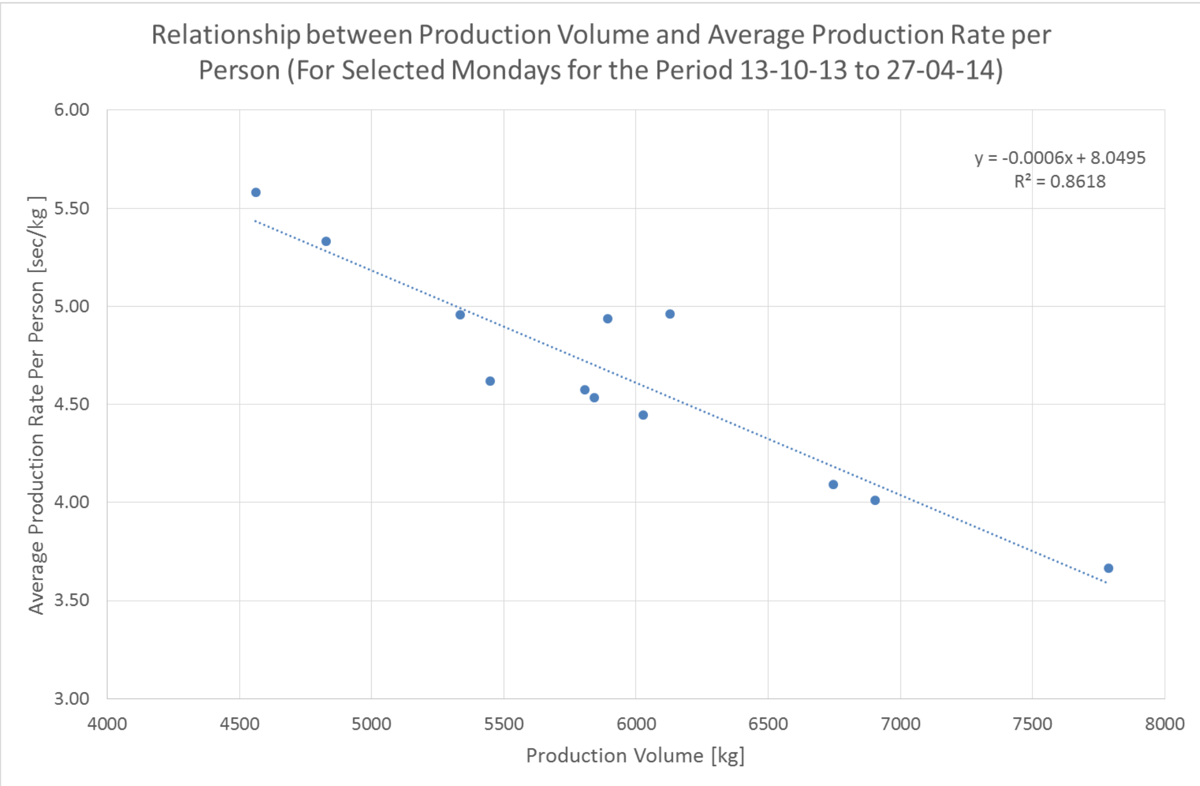


Figure 68. This graph shows a possible explanation for the increased variability observed in for SPT compared to AAPT. The average production rate per person depends strongly (R^2=08618) on the required daily production volume.

Figure 68 shows that, when the required production volume for a day was 4500 kg, it took one operator 5.5 seconds to process 1 kg of product. On the other hand, when the required production volume for a day was 7500 kg, it took one operator 3.75 seconds to process 1 kg of product. Taking note that the number of change-overs required for low production volumes is about the same as for high production volumes – product mix is staying the same – we can discard the hypothesis that the reduced efficiency was caused by increased change-over times.

A closer inspection of the average time worked by each operator on any given day revealed that the time worked by each operator is approximately 8 hours. What can be deduced from this is that there might have existed a social contract amongst operators to aim for an 8 hour work day, regardless whether demand was high or low. There are several ways in which operators might have manipulated their production rate, and, in effect, reduced total production time variability:

I. The operators engaged in activities that were productive but which could not be measured directly in units of seconds/kg.

II. The operators were slowing down production when the required production volume for the day was low, or were speeding up production when required production volume for the day was high.

III. The operators engaged in activities that were unproductive.

Implementing the above mentioned constraints would increase the complexity of the model tremendously. Operator's variable production rate would have to be modelled, requiring every stochastic variable in every activity in the model relating to production time to be monitored and gauged against a standard. Adjustment of operator efficiencies would have to be made accordingly: modelling increased operator efficiency when, say, product arrived late and production volume was high, and modelling decreased operator efficiency when a product arrived early and production volume was low. All of this would have to happen during the simulation run.

Being limited by the time available for the project, the author opted for taking notice of the discrepancy between AAPT and current state SPT, but to continue working with the available simulation model. The rationale behind it being that meaningful results still could be obtained because the efficacy of modelled future state interventions would be measured as a divergence from current state SPT. In practise this meant that, although current state SPT might not display the same variability as AAPT, an increase or decrease in variability in future state SPT compared to current state SPT would still translate into an increase or decrease in variability in AAPT. Likewise, an increase or decrease in median processing time for future state SPT compared to current state SPT would still translate in an increase or decrease in median processing time in AAPT.

For the purpose of analysing of the results from the future state simulation models, the current state model utilisation statistics were obtained and are presented in Table 12. Indivudual worker utilisation and worker pool utilisation are presented in Figure 69, and Figure 70 respectively.

In the VA plant six machines are used for processing product. From the resource statistics presented in Figure 71 to Figure 76 we can deduce machine utilisation for those six machines.

Table 12. Statistics for current state simulation time.

Measure	Current state Simulation Production Time [hh:mm:ss]
min	6:39:41
25th %	7:12:37
median	7:42:18
75th %	8:36:51
max	9:46:04

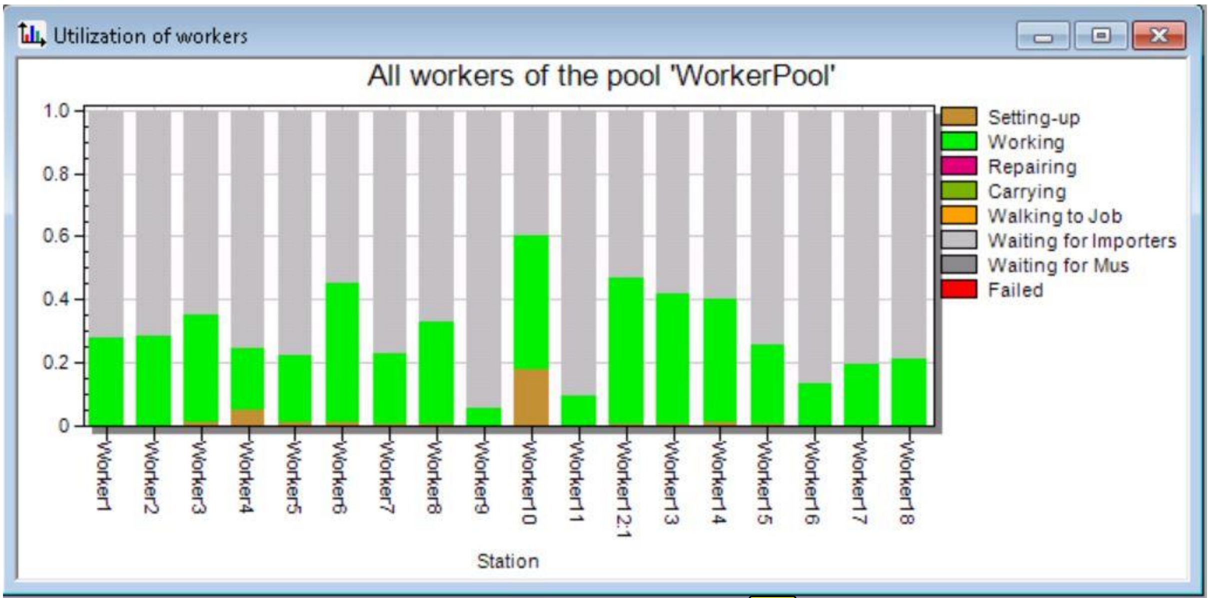


Figure 69. Current state: Individual worker utilisation

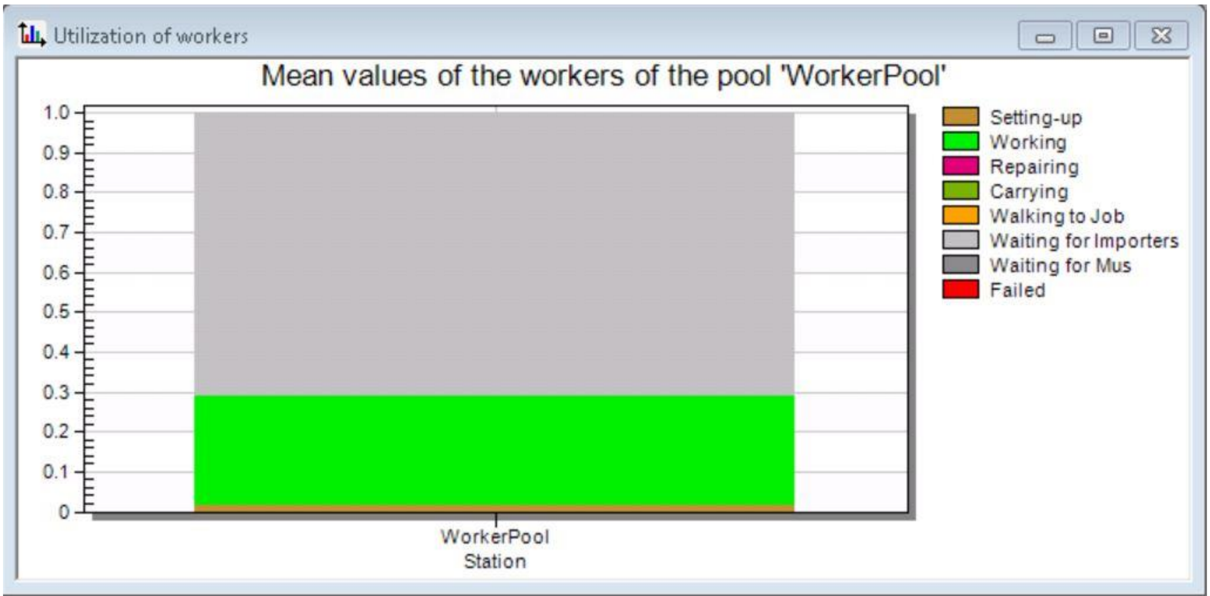


Figure 70. Current state: Worker pool utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Trayseal	9.90%	0.00%	78.08%	12.02%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 71. Current state: Activity C1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
TrayWrapper	32.88%	0.00%	38.49%	24.24%	0.00%	4.39%	0.00%	0.00%	0.00%	

Figure 72. Current state: Activity C2 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
SH	10.02%	6.06%	53.02%	27.40%	0.00%	3.50%	0.00%	0.00%	0.00%	

Figure 73. Current state: Activity A8.3 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Cutting	13.78%	0.00%	42.34%	43.88%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 74. Current state: Activity A8.7 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler1	53.63%	0.00%	46.37%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 75. Current state: Activity A5.1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler2	48.76%	0.00%	51.24%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 76. Current state: Activity A5.2 utilisation.

5.6 Execution of simulation runs

The company saw the need to investigate scenarios by which allergen control could be implemented more effectively. Three scenarios were identified:

1. Implementation of temporal separation between products by ways of random product mix and fixed-time cleaning schedule.
2. Implementation of temporal separation between products by ways of scheduled product mix and variable-time cleaning schedule.
3. Implementation of spatial separation between products by ways of running two identical packaging lines: one for plain product, one for product containing allergens.

In addition, the company wanted to gain more insight into what effect proximity of process lines to the storeroom had on labour costs. Which gave rise to a fourth simulation scenario:

4. Optimising plant layout based on consumables used on the process lines (trays, film, labels, and bags) and process line proximity to the storeroom.

In order to help answer these questions, four experiments where performed using the simulation model. Each experiment uses the same dates for providing the historical production data. For each day providing production data – 13 in total – the simulation was replicated 140 times. In total this became 1820 observations per experiment.

For each replication of the experiment the stochastic variables, such as product arriving time, and processing time changed randomly according to assigned distributions. After each replication the random number seed is changed by the simulation software. Hence, the stochastic values behave randomly assuring more realistic results.

To administer the experiments, Tecnomatix uses a tool called Experiment Manager. The data generated by the experiments is collected in the Experiment Manager, and made accessible for further analyses. The obtained data from the Experiment Manager was used to determine the median values, the 25th and 75th percentile, upper and lower limits, and outliers and extremes. The confidence level used for the experiments was 95%.

5.6.1 Experiment 1: Implementation of temporal separation between products by ways of random product mix and fixed-time cleaning schedule.

Scheduling the product processing sequence in VA in order to implement allergen control requires product processing sequence scheduling to be introduced to processes upstream as well. The ideal sequence in which the product is processed in VA translates in a required sequence of processing for processes upstream. But, what might be an ideal sequence for VA, might not be an ideal sequence for the processes upstream.

The Company wanted to know the increase in labour cost when implementing an allergen control strategy which does not require the scheduling of product based on allergen content. Allergen control is achieved by implementing a fixed-time cleaning regime. The fixed-time cleaning regime consists of cleaning the process lines every time when change-over occurs in preparation for the next product to be produced.

Additional assumption for experiment 1.

- Product arrives at VA in a sequence as is observed in the current state simulation model.
- Required cleaning time for a fixed-time cleaning regime is 4 minutes.

5.6.2 Experiment 2: Implementation of temporal separation between products by ways of scheduled product mix and variable-time cleaning schedule.

The Company wanted to know the increase in labour cost when implementing an allergen control strategy which requires the scheduling of product based on allergen content. Scheduling based on allergen content means that product with the least number of allergens is produced first, followed by products containing an increasing number of allergens. No major cleaning is required during change over as long as the product to be produced next on the production line contains all the allergen present in the product preceding it.

The author compiled an allergen content table for every process line in VA. The allergen content table was used to determine the sequence of production and what type of cleaning was required during change-over. For example, from Table 13, it can be deduced that only one major clean is required. The major clean is required between product 461011 and product 461035. This because product 461011 contains a sulphite that is not present in product 461035. For a complete list of allergen control date see Appendix B.

Additional assumption for experiment 2.

- Product arrives at VA in a sequence so that temporal separation can be implemented.
- Required cleaning times for a variable-time cleaning regime are: 4 minutes when changing over from a product containing an allergen to a product not containing that same allergen, and 30 seconds otherwise.

Table 13. Allergen content of products produced on process line A6/C2/D1

Product Code	Component Code	Gluten	Soy	Milk	Egg	Tree Nuts	Sesame	Sulphites	No Allergen
460915	440170							x	
	440415								
	441073								
	449071	x							
		x						x	
461011	440170							x	
	440415								
	441073								
	449071	x							
		x						x	
461035	440877		x	x					
	449071	x							
	449116			x					
		x	x	x					
461110	440877		x	x					
	449071	x							
	449116			x					
		x	x	x					
461622	441992	x	x					x	
	449071	x							
	449116			x					
		x	x	x				x	
461721	441992	x	x					x	
	449071	x							
	449116			x					
		x	x	x				x	
460038	440041		x					x	
	449071	x							
	449116			x					
		x	x	x				x	
460939	440041		x					x	
	449071	x							
	449116			x					
		x	x	x				x	

5.6.3 Experiment 3: Implementation of spatial separation between products by ways of running two identical packaging lines: one for plain product, one for product containing allergens.

The company anticipates an increase in sales of plain product destined for the export market. It is crucial that the product is delivered on time and produced to specification. In the past, these requirements could sometimes not be met because of problems arising from plain product being processed on a process line on which product containing allergens was processed also. Introducing a second identical packing machine will require normalisation of packing material such as trays and seals. Once trays and seals are normalised, any product, regardless of what process line it is made on, when it contains plain product, it can be packed on a 'clean' line.

For that reason the company wanted to know what the effects are on labour cost when running two identical packaging machines side by side: one for processing plain product, the other one for processing product containing allergens.

Additional assumption for experiment 3.

- The tray wrapper is replaced with a tray sealer.
- The tray sealer introduced to the plant behaves identical to the tray sealer already present in the plant. That is, it produces product at the same rate, requires the same amount of maintenance, and requires the same amount of cleaning.
- The introduction of a second tray sealer requires a re-allocation of jobs to operators.
- Product containing allergens are processed according to a random product mix and fixed-time cleaning schedule scenario.

5.6.4 Experiment 4: Optimised plant layout based on consumables used on the process lines and process line proximity to the storeroom.

In order to be able to monitor the number of product produced during a production run, consumables, such as trays and boxes, were counted prior to production. During production operators then only had to match product with the number of trays and boxes, and were not required to keep count of the number of products produced. A problem arises when a counted consumable had to be discarded: it needed to be replaced, and a trip to the store room had to be undertaken. Due to the large number of different products being processed, change-overs were frequent, and, as a direct result, trips to the store room had to be made frequently as well.

The position of the machines in the plant had never been analysed before and had come about due to gradual changes made to the plant over time. A major concern for the Company was that the process lines using a large amount of consumables were furthest away from the storeroom, while process lines using few consumables were positioned close to the store room. Further variables to consider were the number of required change-overs and production volume. For that reason the company wanted to investigate how to optimise the plant layout, based on consumables used on the process lines and proximity to the storeroom.

For the purpose of analysis, the plant was divided into 3 equal areas (Figure 77). Each area had assigned to it the approximate time it would take to get to the store and back (Table 14). The time required to collect a consumable for a particular production line, would be the time assigned to the area the process line was positioned in. For example, in the current state layout it would take, on average, 95 seconds to collect from the store room a consumable used on process line B2/C2/D1. Whereas, if, in a future state, this process line would be positioned closer to the store (Figure 78), it would take, on average, 35 seconds to collect a consumable from the store room.

For the experiment the times associated with the three areas were assigned to the appropriate process lines.

Additional assumption for experiment 4.

- On average, one trip to the store room has to be made for every change-over between products.
- Times to get to the store and back to the process line are as those presented in Table 14. Initial times chosen were estimations, but the times as presented in the table have been arrived at through an iterative process during calibration of the model.
- The experiment is executed without implementing an allergen control strategy.

Table 14. Time to collect consumables from the store room.

	Mean [sec]	Standard deviation [sec]	Minimum [sec]	Maximum [sec]
Area 1	35	2	29	41
Area 2	65	2	59	71
Area 3	95	2	89	101

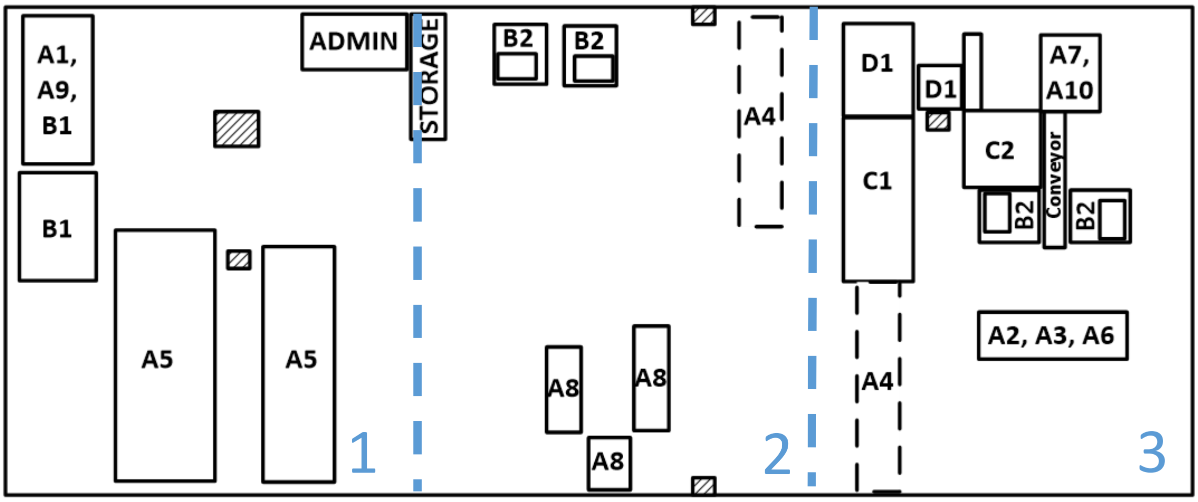


Figure 77. Current state: store room proximity plant layout. Acces to the store is at the bottom left corner of the plant, placing area 1 closest to the store, and area 3 furthest away from the store. Process lines A4/C1/D1 and B2/C2/D1 are placed in area 3, but require consumables for processing.

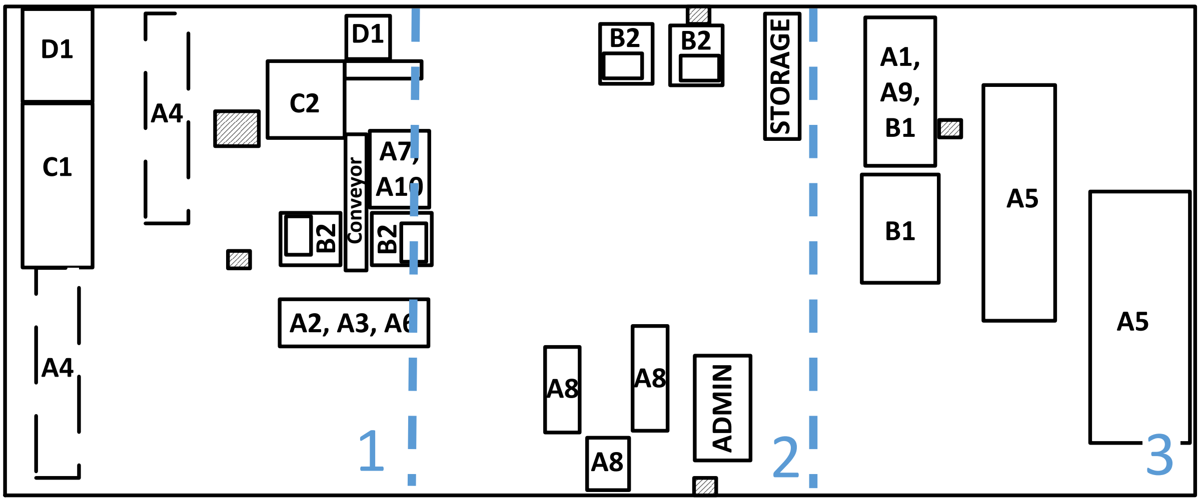


Figure 78. Future state: store room proximity plant layout. The proposed plant layout is to keep area 2 the same, but swap machines in area 1 and area 3 placing process lines A4/C1/D1 and B2/C2/D1 closest to the store room.

5.7 Stage 3 result analysis and interpretation

5.7.1 Experiment 1: Implementation of temporal separation between products by way of random product mix and fixed-time cleaning schedule.

The following results were obtained for experiment 1. From these results we can deduce that implementing temporal separation between products by ways of random product mix and fixed time cleaning schedule results in an increase in median production time and an increase in variability compared to the current state simulation production time (Figure 79). When we compare current state with future state we observe an increase for the median production time by 1 hour 10 minutes (≈ +15% labour cost) and an increase for variability by approximately 25% (Table 12, Table 15).

The utilisation of the combined worker pool shows that, for experiment 1, about 70% of available time was spent on waiting for importers, and 30% was spend on working/setting up (Figure 81). 'Waiting for importers' is the term Tecnomatix uses to describe the situation where a worker is available to perform work, but no 'request' is made by a machine to have work performed associated with that machine.). This suggest that, compared to the current state, although the overall time spend on working/setting up remained the same, a slightly larger proportion of the overall time was spend on setting up.

Comparing the resource statistics for experiment 1 with the resource statistics for the current state, we see no significant change in machine utilisation (Figure 71, Figure 72, Figure 84, Figure 85, Figure 86, and Figure 87). The change that is observed can be explained by the stochastic behaviour of the time product is arriving at the processes.

Table 15. Statistics for future state: random product mix and fixed cleaning schedule.

Measure	Future State: Random Product Mix and Fixed Cleaning Schedule [hh:mm:ss]
min	6:50:11
25th %	7:59:37
median	8:53:15
75th %	9:36:37
max	10:53:41

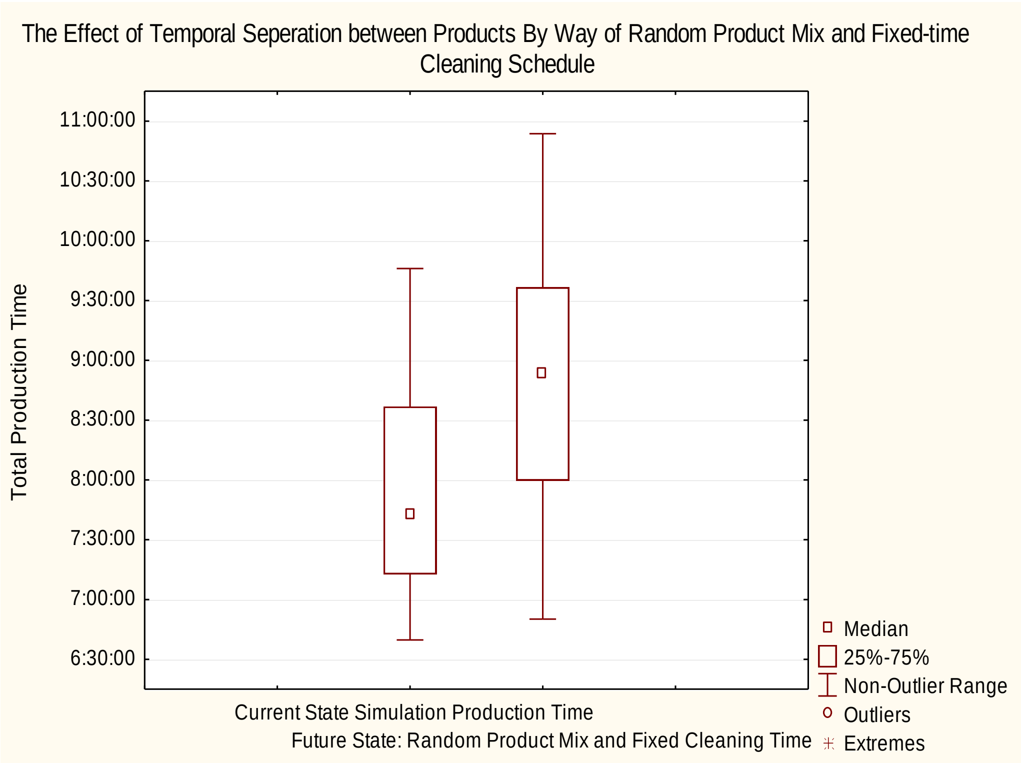


Figure 79. Comparing the current state simulation prodution time to the future state simulation production time based on a random product mix and fixed cleaning time regime. Observed are an increase in median production time and an increase in variability.

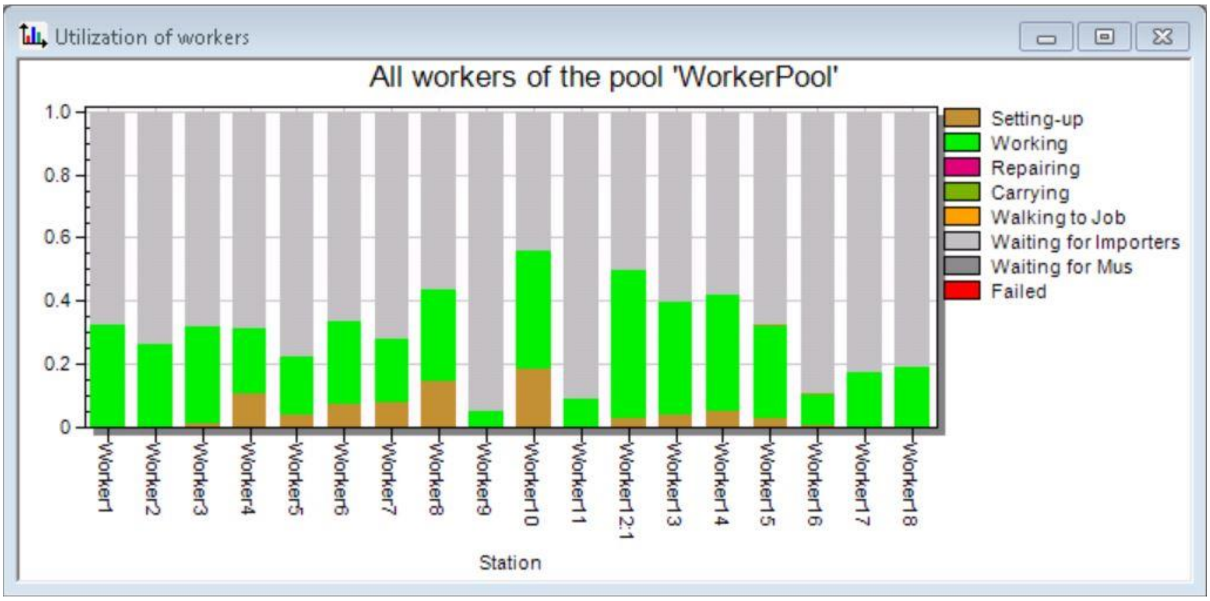


Figure 80. Experiment 1: Individual worker utilisation.

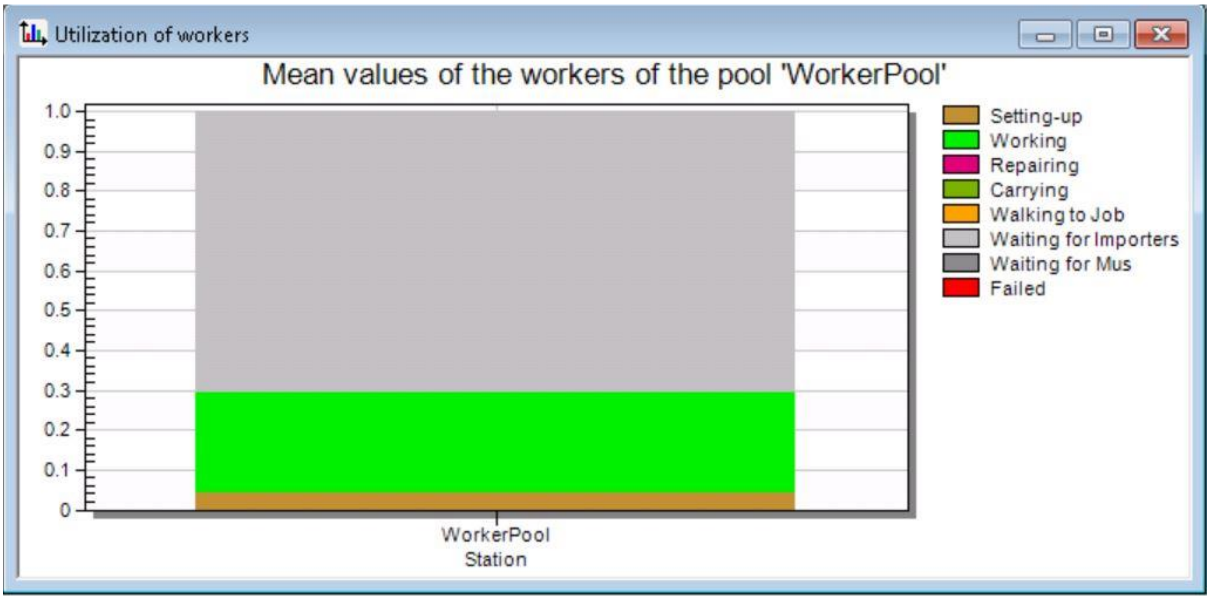


Figure 81. Experiment 1: Worker pool utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Trayseal	8.80%	0.00%	77.97%	13.23%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 82. Experiment 1: Activity C1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
TrayWrapper	29.22%	0.00%	53.66%	13.22%	0.00%	3.90%	0.00%	0.00%	0.00%	

Figure 83. Experiment 1: Activity C2 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
SH	8.91%	5.39%	58.32%	24.27%	0.00%	3.11%	0.00%	0.00%	0.00%	

Figure 84. Experiment 1: Activity A8.3 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Cutting	12.24%	0.00%	37.69%	50.06%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 85. Experiment 1: Activity A8.7 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler1	47.67%	0.00%	52.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 86. Experiment 1: Activity A5.1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler2	43.34%	0.00%	56.66%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 87. Experiment 1: Activity A5.2 utilisation.

5.7.2 Experiment 2: Implementation of temporal separation between products by way of scheduled product mix and variable-time cleaning schedule.

The following results were obtained for experiment 2. From these results we can deduce that implementing temporal separation between products by ways of scheduled product mix and variable-time cleaning schedule results in an increase in median production time and an increase in variability (Figure 88). When we compare current state with future state we observe an increase for the median production time by 20 minutes (≈ +4% labour cost) and an increase of variability by approximately 14% (Table 12, Table 16).

The utilisation of the combined worker pool suggests that, for experiment 2, about 77% of available time was spent on waiting for importers, and 23% was spent on working/setting up (Figure 90). From this we can deduce that the same amount of product is produced in less time with a scheduled product mix than with the current state. Also, it suggests that the same amount of product is produced in less time with a scheduled product mix than with a random product mix. Which is understandable since, less time is spent on cleaning during change-overs.

Comparing the resource statistics for experiment 2 with the resource statistics for current state, we see a change in the utilisation of activity C1 and C2 (Figure 91, Figure 92). The percentage working for activity C1 has increased by approximately 4%, while the percentage working for activity C2 has decreased by 12%.

Likewise, for activity A8.3 and A8.7 a change is observed, namely a decrease of 5% and 7% respectively (Figure 93, Figure 94).

On the other hand for activity A5, no significant change was observed (Figure 75, Figure 76).

Table 16. Statistics for future state: scheduled product mix and variable cleaning time.

Measure	Future State: Scheduled Product Mix and Variable Cleaning Time [hh:mm:ss]
min	6:39:41
25th %	7:17:33
median	8:02:18
75th %	9:00:52
max	10:16:19

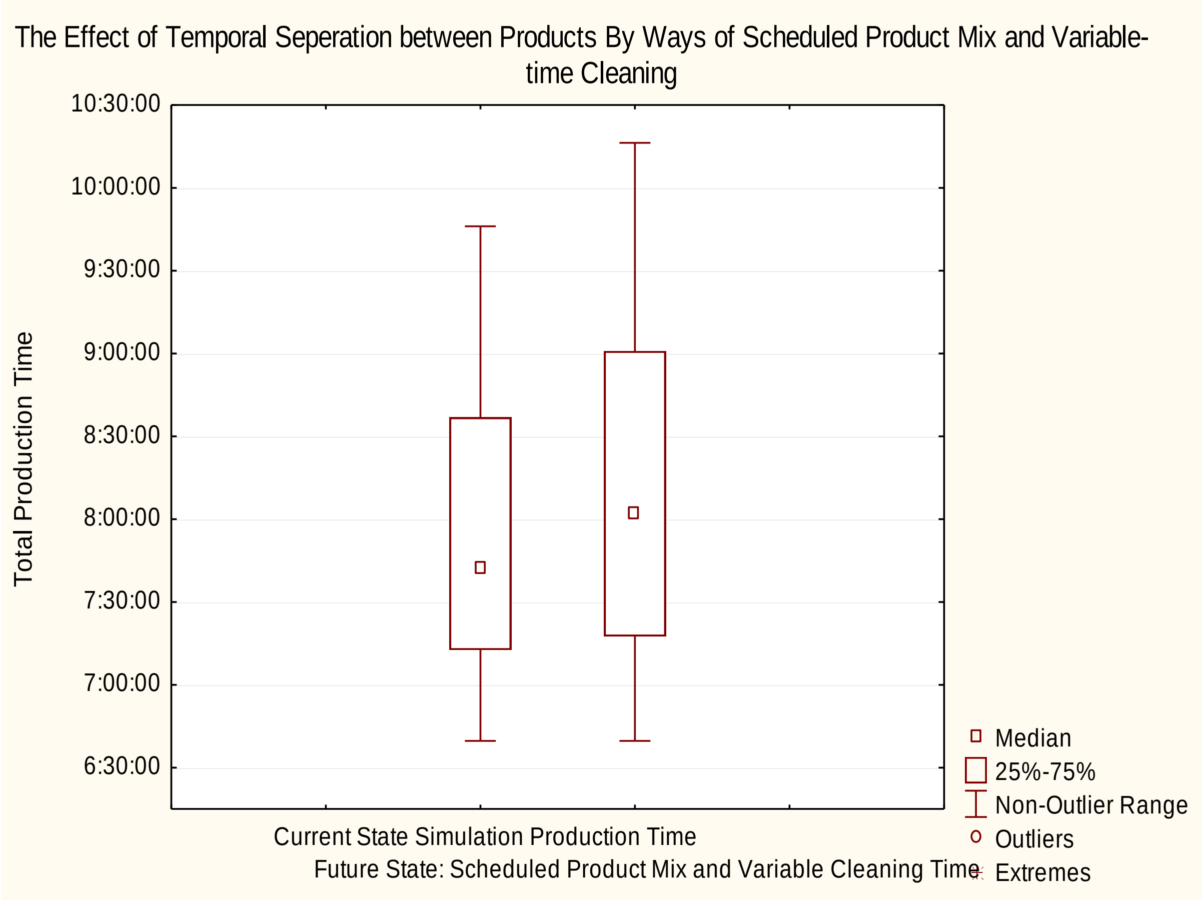


Figure 88. Comparing the current state simulation prodution time to the future state simulation production time based on a scheduled product mix and variable cleaning time regime. Observed are an increase in median production time and an increase in variability.

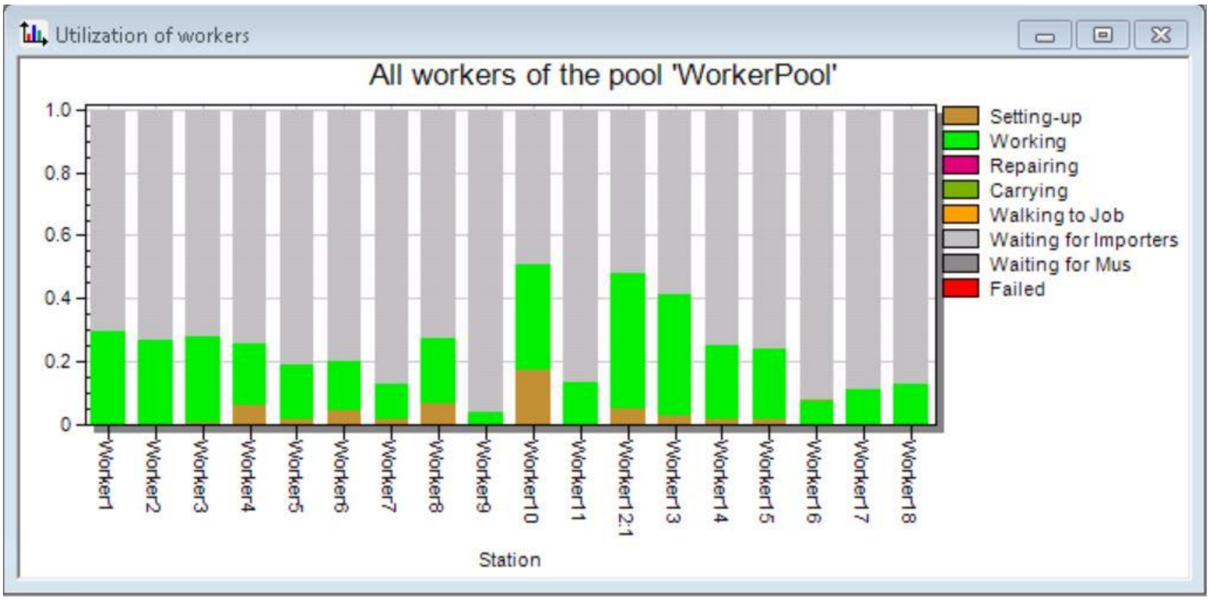


Figure 89. Experiment 2: Individual worker utilisation.

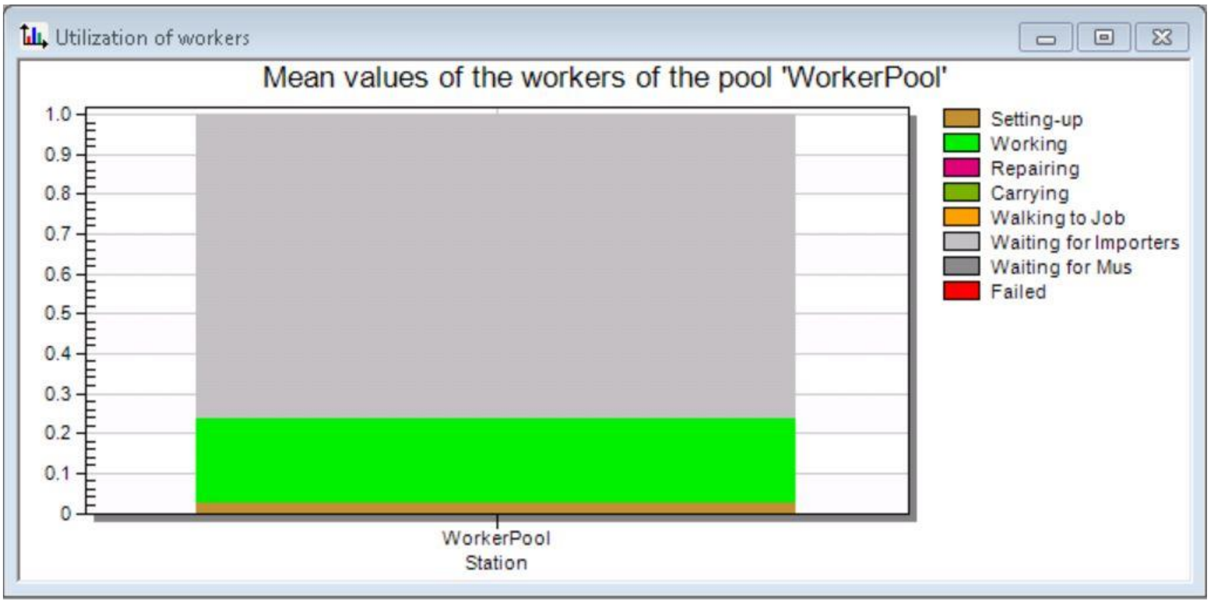


Figure 90. Experiment 2: Worker pool utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Trayseal	13.88%	0.00%	67.86%	18.25%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 91. Experiment 2: Activity C1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
TrayWrapper	20.40%	0.00%	57.64%	17.85%	0.00%	4.11%	0.00%	0.00%	0.00%	

Figure 92. Experiment 2: Activity C2 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
SH	4.71%	5.68%	65.38%	20.95%	0.00%	3.28%	0.00%	0.00%	0.00%	

Figure 93. Experiment 2: Activity A8.3 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Cutting	6.42%	0.00%	32.47%	61.12%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 94. Experiment 2: Activity A8.7 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler1	50.27%	0.00%	49.73%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 95. Experiment 2: Activity A5.1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler2	50.27%	0.00%	49.73%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 96. Experiment 2: Activity A5.2 utilisation.

5.7.3 Experiment 3: Implementation of spatial separation between products by way of running two identical packaging lines: one for plain product, one for product containing allergens.

The following results were obtained for experiment 3. From these results we can deduce that implementing spatial separation between products by ways of running two identical packaging lines: one for plain product, one for product containing allergens, results in an increase in median production time and an increase in variability. When we compare current state with future state we observe an increase for the median production time by 20 minutes (≈ +4% labour cost) and an increase of variability by approximately 25% (Table 12, Table 17). It must be noted that the increase of variability is calculated ignoring the outliers and extremes.

The utilisation of the combined worker pool suggests that, for experiment 3, about 77% of available time was spent on waiting for importers, and 23% was spent on working/setting up (Figure 99). From this we can deduce that the same amount of product is produced in less time with two identical packing lines than with the current state. Even though slightly more time is spend on setting up.

Comparing the resource statistics for experiment 3 with the resource statistics for current state, we see no significant change in the utilisation of the packing machine that replaced the packing machine in activity C2 (Figure 100). What has changed is the utilisation of the original machine. The percentage working for activity C1 has decreased by approximately 8% (Figure 101).

Likewise, for activity A8.3 and A8.7 a change is observed, namely a decrease of 5% and 7% respectively (Figure 102, Figure 103).

On the other hand for activity A5, no significant change was observed (Figure 95, Figure 96).

Table 17. Statistics for future state: two identical packing lines.

Measure	Future State: Two Identical Packing Lines [hh:mm:ss]
min	6:33:02
25th %	7:32:35
median	8:03:11
75th %	8:50:05
max	14:47:24

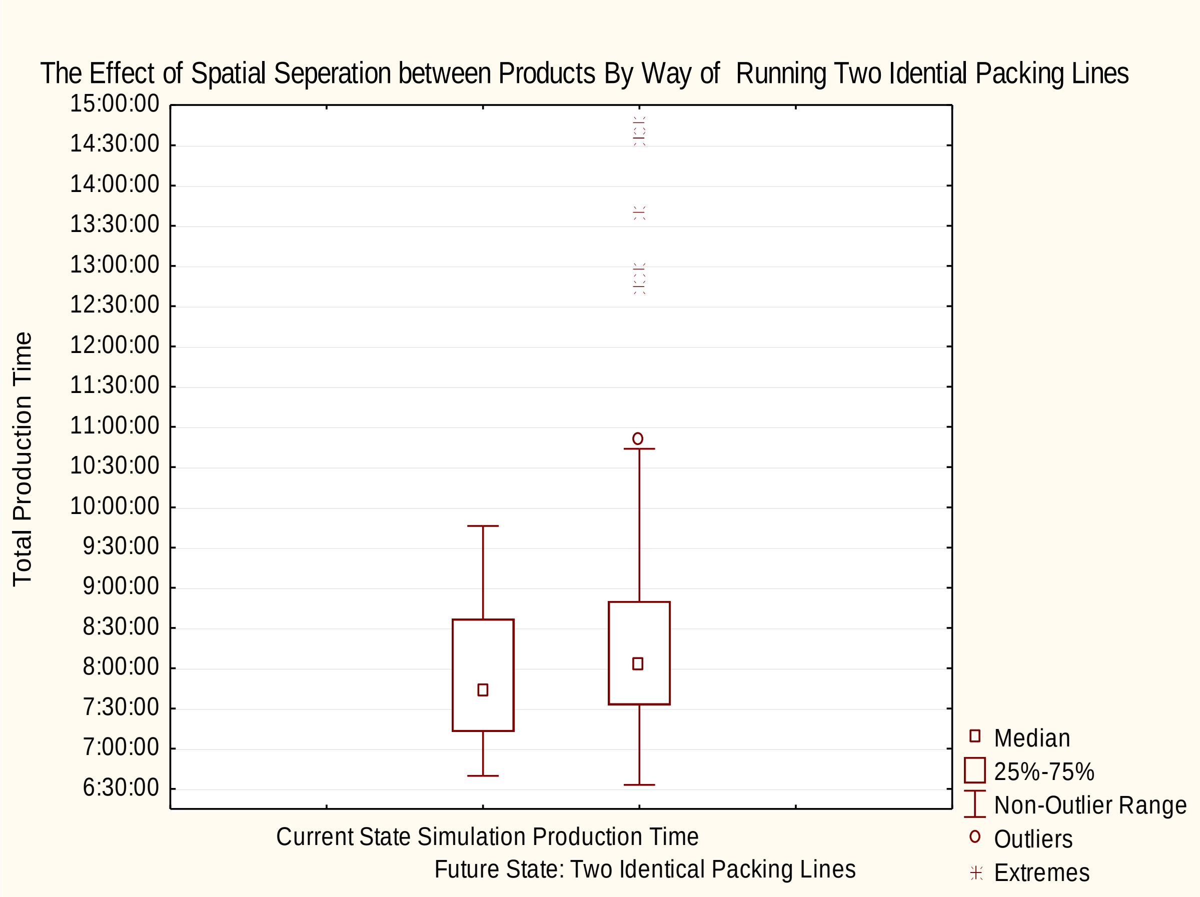


Figure 97. Comparing the current state simulation prodution time to the future state simulation production time based on two identical packing lines. Observed are an increase in median production time and a significant increase in variability.

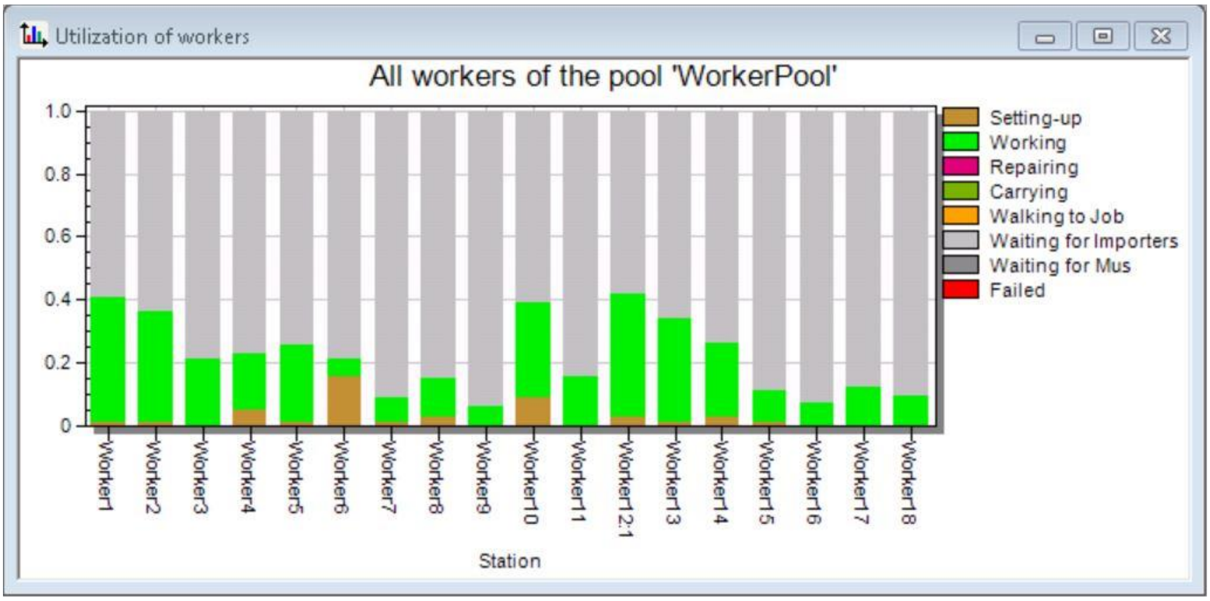


Figure 98. Experiment 3: Individual worker utilisation.

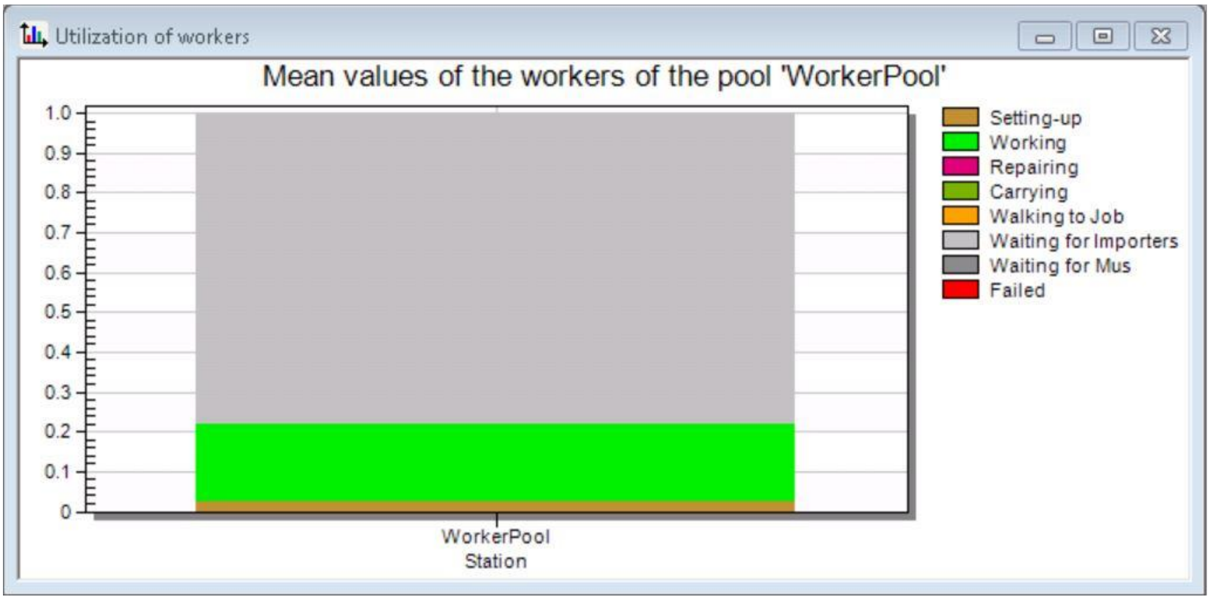


Figure 99. Experiment 3: Worker pool utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Trayseal	32.50%	0.00%	53.05%	14.45%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 100. Experiment 3: Activity C1.1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Trayseal	1.81%	0.00%	97.29%	0.89%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 101. Experiment 3: Activity C1.2 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
SH	4.94%	1.86%	85.71%	4.28%	0.00%	3.21%	0.00%	0.00%	0.00%	

Figure 102. Experiment 3: Activity A8.3 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Cutting	6.74%	0.00%	12.17%	81.09%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 103. Experiment 3: Activity A8.7 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler1	49.15%	0.00%	50.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 104. Experiment 3: Activity A5.1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler2	49.15%	0.00%	50.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 105. Experiment 3: Activity A5.2 utilisation.

5.7.4 Experiment 4: Optimised plant layout based on consumables used on the process lines (trays, film, labels, bags) and process line proximity to the store room.

The following results were obtained for experiment 4. From these results we can deduce that optimising plant layout based on consumables used on the process line and process line proximity to the store room results in a decrease in median production time and a decrease in variability (Figure 106). When we compare current state with future state we observe a decrease for the median production time by 8 minutes ($\approx -2\%$ labour cost) and a decrease of variability by approximately 10% (Table 12, Table 18).

The utilisation of the combined worker pool shows that, for experiment 4, about 77% of available time was spent on waiting for importers, and 23% was spent on working/setting up (Figure 108). From this we can deduce that the same amount of product is produced in less time with swapped plant than with the current state.

Comparing the resource statistics for experiment 4 with the resource statistics for current state, we see a change in the utilisation of activity C1 and C2 (Figure 109, Figure 110). The percentage working for activity C1 has increased by approximately 4%, while the percentage working for activity C2 has decreased by 12%.

Likewise, for activity A8.3 and A8.7 a significant change is observed, namely a decrease of 5% and 7% respectively (Figure 111, Figure 112).

But, as before, for activity A5, no significant change was observed (Figure 113, Figure 114).

Table 18. Statistics for future state: plant swap.

Measure	Future State: Plant Swap [hh:mm:ss]
min	6:39:41
25th %	7:09:06
median	7:34:17
75th %	8:18:17
max	9:29:40

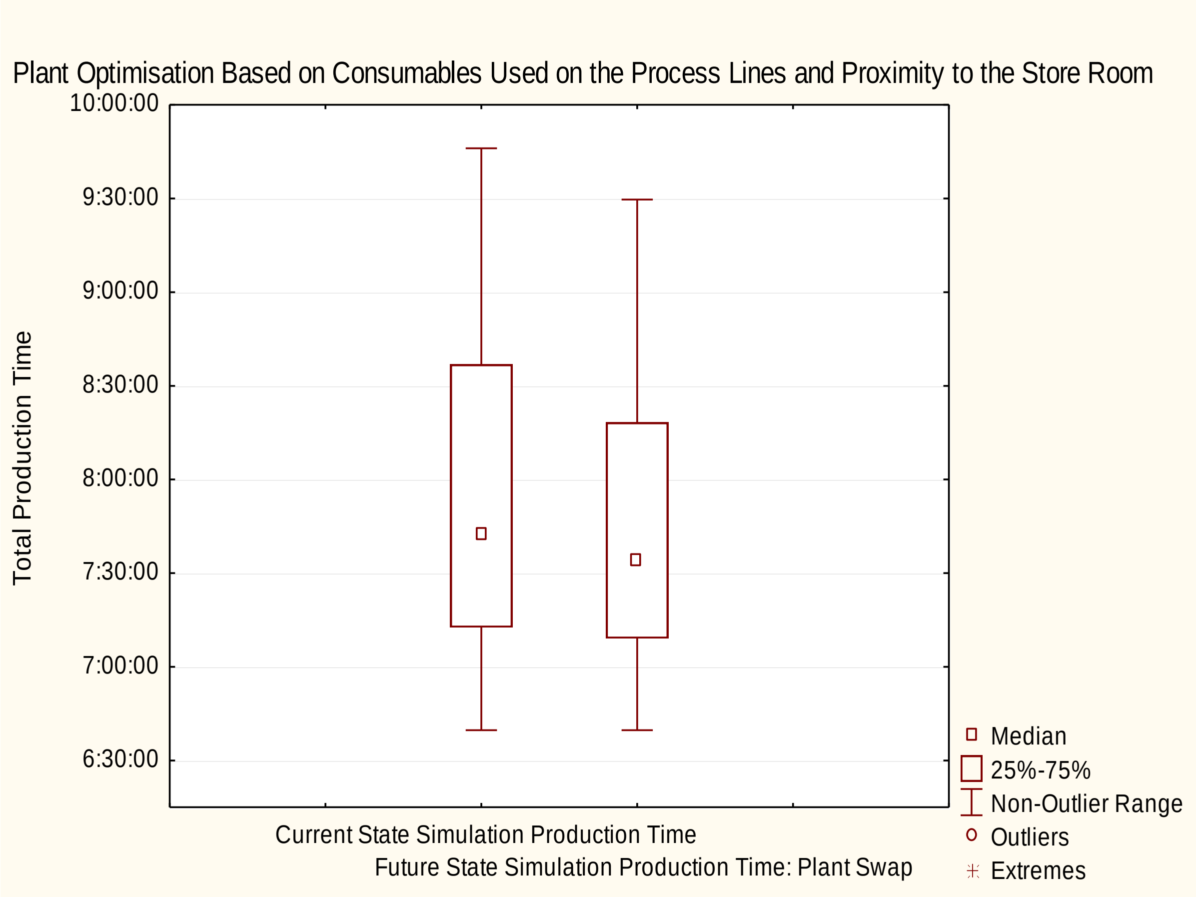


Figure 106. Comparing the current state simulation prodution time to the future state simulation production time based on a plant swap. Observed are a decrease in median production time and a decrease in variability.

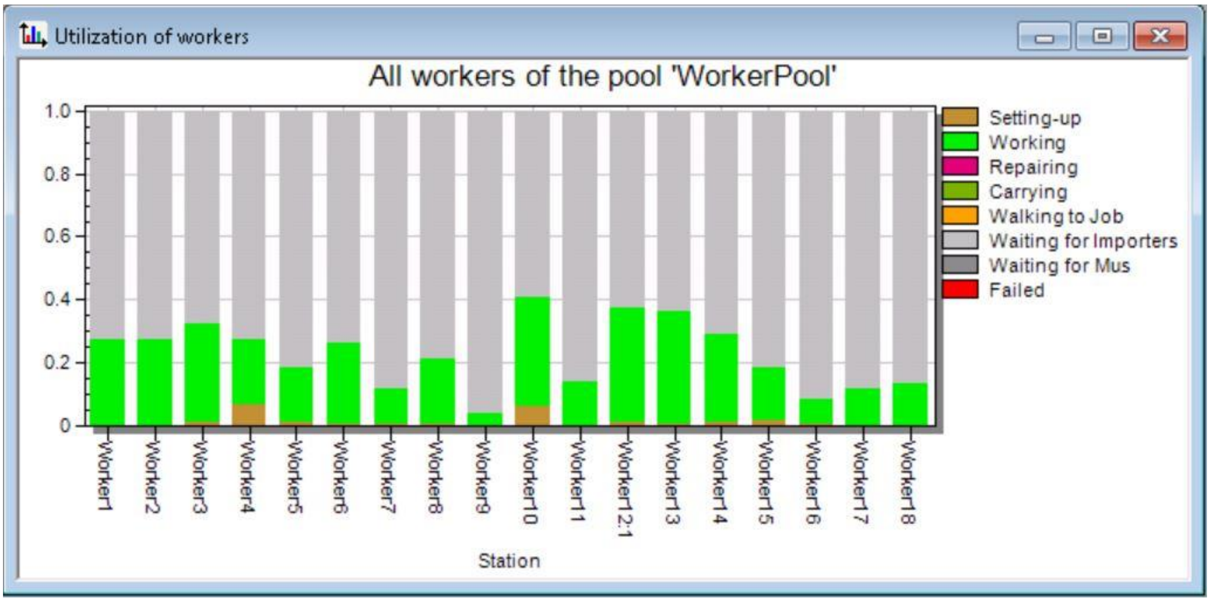


Figure 107. Experiment 4: Individual worker utilisation.

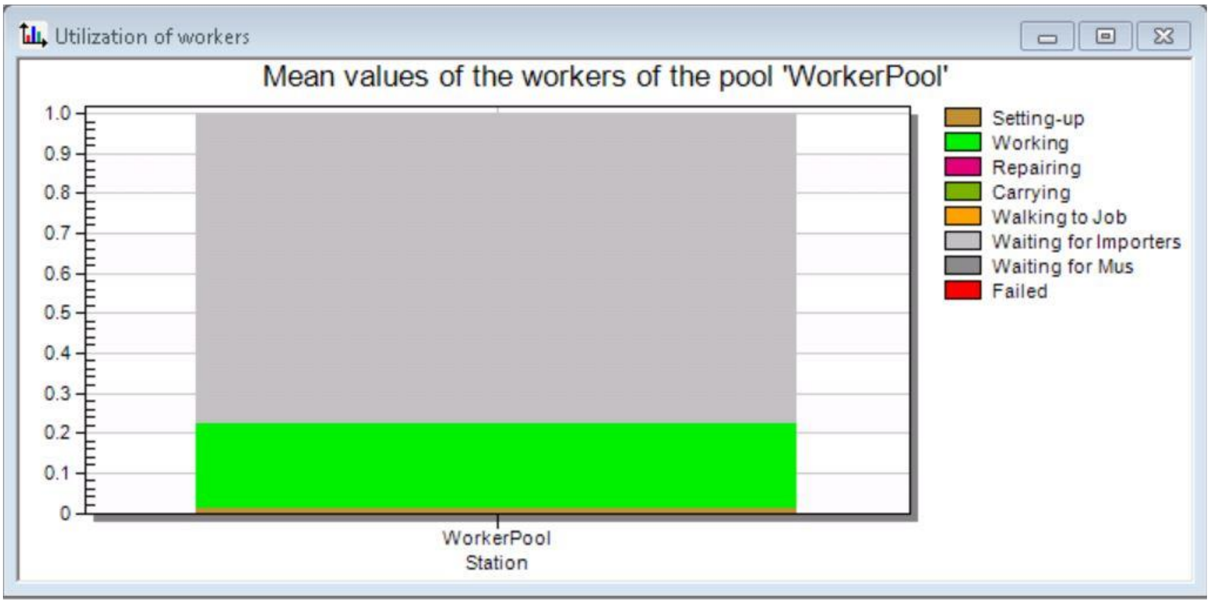


Figure 108. Experiment 4: Worker pool utilisation

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Trayseal	14.30%	0.00%	74.29%	11.42%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 109. Experiment 4: Activity C1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
TrayWrapper	21.00%	0.00%	59.68%	15.08%	0.00%	4.23%	0.00%	0.00%	0.00%	

Figure 110. Experiment 4: Activity C2 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
SH	4.85%	5.85%	64.35%	21.57%	0.00%	3.38%	0.00%	0.00%	0.00%	

Figure 111. Experiment 4: Activity A8.3 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Cutting	6.61%	0.00%	33.43%	59.96%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 112. Experiment 4: Activity A8.7 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler1	51.76%	0.00%	48.24%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 113. Experiment 4: Activity A5.1 utilisation.

Resource Statistics - Resource Statistics

Portions of the States of the Statistics Collection Period

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Tumbler2	51.76%	0.00%	48.24%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 114. Experiment 4: Activity A5.2 utilisation.

Chapter 6
Discussion

6.1 Project outcomes

The original purpose of this work was to provide an integrated solution to the problem of optimising plant production flow while also optimising allergen control. That is, to improve process flows, improve equipment utilisation, reduce work-in-process (WIP) inventory, and reduce unnecessary movement of stock while also optimising allergen control in the area under investigation.

In this work a model has been developed that identifies, in a plant with multiple process lines and shared resources, the areas of priority where to start VSM analysis. The model integrates functional layout, spatial layout, and flow and time dimensions of a plant. While PQ analysis allows for a selection based on volume or production cost, and a functional layout of the plant allows for selection based on product groups, adding the additional step of drawing up a spatial layout allows for evaluation of physical distances. The premise being that where physical distances exist, transport of WIP is required, which in turn causes the amount of WIP to increase because of batching. Also, in a food processing FMCG plant where product containing allergens is being processed, the movement of product needs to be kept to a minimum in order to keep allergen contamination risk to a minimum. Therefore, having a model at disposal to determine which process is most likely to generate cost savings, while also evaluating allergen cross contamination risk, is invaluable. Adding the additional step of drawing up a spatial layout gives an increased level of certainty the efforts going towards setting up VSMs will actually be directed towards the process that is likely to be most wasteful and prone to cross contamination risk.

This work is an affirmation that implementation of lean manufacturing principles to an FMCG plant can deliver prolonged positive results, save a relation of trust exists between the practitioner and staff. Specifically, we have shown that the practitioner working alongside operators on shop floor level allows for process improvement efforts being introduced to a team that thus far had been vehemently opposed to change. A three stage strategy was applied. In the first stage the practitioner was working alongside plant operators; introducing changes in line with the 5S methodology. The changes mainly concerned "housekeeping". The second stage, building on the trust gained during stage one, saw the introduction of changes instigated by individual process analysis using VSMs and line balancing. The third stage of the strategy was the evaluation of allergen control strategies for plant layout using specialised software. In this case Siemens Tecnomatix simulation software. Throughout the project, trial runs were held for each proposed change. After each trial-run an informal meeting was held in which staff was encouraged to give feedback and come to conclusion whether to proceed with the change or not. Having come to a decision as a group meant in practice that those in the group who were sceptical at first were drawn over the line by their peers rather then being made to comply by management, with something they did not, either comprehend, or appreciate. Not only were staff acceptive and appreciative of the changes the practitioner proposed, they actively collaborated in resolving issues that were hampering more efficient production.

During this project a line balancing tool has been developed that can accommodate *n* concurrent activities for a cyclical process using *i* in-process jigs. The tool allows determining number of operators, number of in-process jigs, activity/operator allocation, and, indirectly, process layout. Cyclical Process with Concurrent Activities (CPCA) balancing can be applied to a process that is cyclical in nature and is made up of multiple activities that are to be executed in a predetermined sequence. The activities have the potential, though, to be executed concurrently, depending on the number of in-line jigs, and on the number of operators on the line. This tool allows the practitioner to quickly and easily determine the optimal configuration for a process for which no intuitive solution exists. Since the tool relies heavily on visual cues, it can also be used to communicate conclusions to staff.

Discrete event simulation software has been used to determine the preferred strategy for implementing allergen control in a food producing FMCG plant. Three preferred allergen control strategies were identified by the Company, which were then modelled and analysed for impact on labour cost, worker utilisation, and machine utilisation. Furthermore, a study was done on the effect of plant layout on labour cost.

6.2 Limitations

The nature of the project, it being a Master project, limited the extent to which the practitioner could apply formal authority. In fact, he had none. It begs the question whether expressed collaboration of staff was based on trust gained during embedment of the practitioner, or on staff being able to 'speak their mind freely' without having to fear repercussions.

Value stream mapping is most commonly used to map value streams "door-to-door" inside a plant. For this project we mapped the value stream inside a sub plant of a larger plant. As such, the use of VSMs might seem excessive and contrived. Nonetheless VSMs, even in the simplified form they were used here, were found to be a useful tool. Not only as an analysis tool, but certainly too as a way of communicating to staff the reason for proposed changes as well as the expected outcomes of these changes.

A PQ analysis was used to determine which products were contributing most to the production cost. A decision was made to model only those products that were contributing most to the cost of production. In hindsight it might have been better to have modelled the entire product mix. It would have made the analysis of simulation results easier. By eliminating part of the production portfolio, a scaling factor had to be introduced which might make the results look contrived.

6.3 Future work

It was assumed that Monday's production volumes and product mix is a representative for average daily production volumes and product mix throughout the week. The decision to make this assumption was mainly driven by the constraint on time available. The software became available in April of 2014, 7 months after commencement of the project in August 2013. Although the assumption is valid, it certainly has an effect on the results of the simulation. Further research is warranted.

Three allergen control strategies were modelled. From the simulation results it became clear that a possible fourth strategy might exist namely, implementation of spatial separation between products by way of running two identical packaging lines. Where, once plain product has been processed, the line becomes available for processing product containing allergens. The processing of product containing allergens would follow the scheduled product mix strategy. Further research is warranted.

Chapter 7
Conclusions and recommendations

The original purpose of this work was to was to provide an integrated solution to the problem of optimising plant production flow while also optimising allergen control. That is, to improve process flows, improve equipment utilisation, reduce work-in-process (WIP) inventory, and reduce unnecessary movement of stock while also optimising allergen control in the area under investigation.

7.1 Process improvement

The process improvement efforts introduced during stage 2 of the project resulted in a 7% savings on labour cost, reduction in plant variability, reduced allergen cross contamination risk, reduced WIP, reduction of consumables, and increased equipment utilisation.

On commencement of the project the VA plant operators were vehemently opposed to change. Due to the nature of a food processing FMCG plant, with its ever changing product mix and production volumes, operators had learned to be cautious with making changes to the plant. After embedment, the researcher found the operators to be acceptive and appreciative of suggested improvement efforts. The proposed changes were communicated to the operators using VSMs, to which they responded well. It was the visual nature of the VSMs that contributed most to their effectiveness. In addition, the proposed changes were addressing the root causes of the problem. A fundamental solution was presented to the operators rather then a temporary fix: they responded with enthusiasm.

With operators having responded well to visual cues, and the ability for them to appreciate the effectiveness of changes made to the processes on a fundamental level, it is recommended for the company to start using control charts to monitor the shifts in the VA processes that alter the mean or variance of a measured statistic. With the ever changing product mix and production volumes the current system of variance analysis is too crude to be able to assign increased production cost to a specific product, production line, or processing method.

The preferred statistic to be measured would have to be the time per day spend on each single production line. This would allow staff, and management, to ‘see’ what is causing the increase of production cost on a daily basis: allowing for targeted improvement efforts. In case time per day spend on each single production line as a statistic is considered too intrusive or too costly, the current statistic of weekly labour cost for the whole plant, expressed in an XmR chart, can be used as well. Bearing in mind though, that an XmR chart is less sensitive to perturbations to the processes.

7.2 Allergen control

From the simulation results the conclusion can be drawn that implementing allergen control comes at a cost. The method that would add the most cost to the labour component would be the implementation of temporal separation between products by way of random product mix and fixed-time cleaning schedule. The production cost would be expected to increase by approximately 15%. The benefit of this method is that no additional cost or efforts would have to go towards scheduling production.

The most cost effective way of implementing allergen control would be to implement temporal separation between products by way of scheduled product mix and variable-time cleaning schedule. The production cost would be expected to increase by approximately 4%. Of course, this method would require additional cost and effort to go towards scheduling production.

Although, implementation of spatial separation between products by way of running two identical packaging lines: one for plain product, one for product containing allergens, results in an increase of labour cost comparable to the scheduled product mix strategy, it significantly increases the variability of the process. It should be noted though that assigning one machine for processing plain product only, would currently utilise the machine less than 2%. Further investigation into a hybrid strategy is warranted. A strategy where, once plain product has been processed, the line becomes available for processing product containing allergens following a scheduled product mix strategy.

To offset the cost of implementing allergen control a plant swap should be considered. Re-organising the plant such that processing lines B2/C2/D1 and A4/C1/D1 are closest to the store, and processing line A5/B1 furthest away, results in approximately 2% savings on labour cost.

References

1. Taylor, F.W., *The principles of scientific management*. 1919, New York: Harper & Brothers Publishers.

2. Sorensen, C.E., *My forthy years with Ford*. 1956, New York: W.W. Norton & Company Inc.

3. Shewhart, W.A., *Economic quality control of manufactured product.* Bell System Technical Journal, 1930. 9(4): p. 364-389.

4. *Deming*, in *The Blackwell Encyclopedia of Management*, N. Slack and M. Lewis, Editors. 2005, Blackwell: Malden, MA. p. 56-57.

5. Ohno, T., *Toyota production system : beyond large-scale production*. 1988, Cambridge, Mass.: Productivity Press.

6. Jones, D.T. and S.J. Prais, *PLANT-SIZE AND PRODUCTIVITY IN THE MOTOR INDUSTRY: SOME INTERNATIONAL COMPARISONS.* Oxford Bulletin of Economics & Statistics, 1978. 40(2): p. 131-151.

7. Abernathy, W.J.C., Kim B.; Kantrow, Allen M., *Industrial Renaissance*. 1983, New York: Basic Books, Inc.

8. *Kanban and just-in-time at Toyota*. 1985, Cambridge, MA: Productivity Press.

9. Sugimori, Y., et al., *Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system.* International Journal of Production Research, 1977. 15(6): p. 553.

10. Deming, W.E., *Quality, Productivity, and Competitive Position*. 1882, Cambridge: MIT.

11. Shonberger, R.J., *Japanese manufacturing techniques*. 1982, New York: The free press.

12. Monden, Y., *Toyota Production System*. 1983, Atlanta: Industrial Engineering and Management Press.

13. Shigeo, S., *A study of the Toyota Production System from an Industrial Engineering Viewpoint*. 1989, Cambridge, MA: Productivity Press.

14. Holweg, M., *The genealogy of lean production.* Journal of Operations Management, 2007. 25(2): p. 420-437.

15. Liker, J.K., *The Toyota way: 14 management principles from the world's greatest manufacturer*. 2004, New York McGraw-Hill.

16. Osada, T., *The 5S's: Five Keys to a Total Quality Environment*. 1991, Minato-ku, Tokyo, Japan: Asian Productivity Organization.

17. Liker, J.K.M., David, *The Toyota way fieldbook: a practical guide for implementing Toyota's 4P's*. 2006, New York: McGraw-Hill.

18. Nash, M.A. and S.R. Poling, *Mapping the Total Value Stream : A Comprehensive Guide for Production and Transactional Processes*, 2011, Taylor and Francis: Hoboken.

19. Rother, M.S.J., *Learning to See*, 2003, The Lean Enterprise Institute: Cambridge, Massachusetts, USA.

20. Scholl, A., *Balancing and Sequencing of Assembly Lines*. 1995, Heidelberg, Germany: Physica-Verlag.

21. Martin, T.D. and J.T. Bell, *New Horizons in Standardized Work : Techniques for Manufacturing and Business Process Improvement*, 2011, Taylor and Francis.

22. Kalpakjian, S.S., S., *Manufacturign engineering and technology*. 4th ed. 2001, Upper Saddle River, NJ: Prentice Hall.

23. Basu, R., *Implementing Six Sigma and Lean*, 2009, Taylor and Francis: Hoboken.

24. Goldratt, E.M.C., Jeff; Whiteford, David, *The goal: a process of ongoing improvement*. 3rd ed. 2004, Aldershot: Gower.

25. Jacobs, F.R., Chase, R. B., *Operations and supply chain management*. 13th ed. 2011, New York: McGraw-Hill.

26. Pyzdek, T., *The Six Sigma handbook: a complete guide for green belts, black belts, and managers at all levels*. 2010, New York: McGraw-Hill.

27. Tompkins, J.A.W., J. A.; Bozer, Y. A.; Tanchoco, J. M. A., *Facilities planning*. 3 ed. 2003, Hoboken: John wiley & Sons, Inc.

28. Buzacott, J.A., *Modelling manufacturing systems.* Robotics and Computer-Integrated Manufacturing, 1985. 2(1): p. 25-32.

29. Dweirt, F. and F.A. Meier, *Application of fuzzy decision-making in facilities layout planning.* International Journal of Production Research, 1996. 34(11): p. 3207.

30. Raoot, A.D. and A. Rakshit, *A 'fuzzy' approach to facilities lay-out planning.* International Journal of Production Research, 1991. 29(4): p. 835.

31. Ross, S.M., *Simulation*. 5 ed. 2013, Amsterdam: Elsevier.

32. Bell, P.C., *Visual Interactive Modeling as an Operations Research Technique.* Interfaces, 1985. 15(4): p. 26-33.

33. Matthews, J., et al. *A constraint-based modelling approach, to assess the capability of food processing equipment to handle product variation*. in *5th International Seminar and Workshop of Engineering Design Integrated Produc5th International Seminar and Workshop of Engineering Design Integrated Product Development: Design Methods for Practice, EDIProD 2006, September 21, 2006 - September 23, 2006*. 2006. Zielona Gora, Poland: The Design Society.

34. Johansson, S.G.O., et al., *Revised nomenclature for allergy for global use: Report of the Nomenclature Review Committee of the World Allergy Organization, October 2003.* Journal of Allergy and Clinical Immunology, 2004. 113(5): p. 832-836.

35. Sicherer, S.H., *Epidemiology of food allergy.* Journal of Allergy and Clinical Immunology, 2011. 127(3): p. 594-602.

36. Ortolani, C. and E.A. Pastorello, *Food allergies and food intolerances.* Best Practice & Research Clinical Gastroenterology, 2006. 20(3): p. 467-483.

37. Clark, J.P., *Allergen-safe processing.* Food Technology, 2005. 59(2): p. 63-64.

38. Bredehorst, R. and K. David, *What establishes a protein as an allergen?* Journal of Chromatography B: Biomedical Sciences and Applications, 2001. 756(1–2): p. 33-40.

39. Rona, R.J., et al., *The prevalence of food allergy: A meta-analysis.* Journal of Allergy and Clinical Immunology, 2007. 120(3): p. 638-646.

40. Zuidmeer, L., et al., *The prevalence of plant food allergies: A systematic review.* Journal of Allergy and Clinical Immunology, 2008. 121(5): p. 1210-1218.e4.

41. Crevel, R., *Responding to allergens.* Food Science and Technology (London), 2012. 26(2): p. 31-33.

42. Pastorello, E.A. and C. Trambaioli, *Isolation of food allergens.* Journal of Chromatography B: Biomedical Sciences and Applications, 2001. 756(1–2): p. 71-84.

43. Gallo, M. and R. Sayre, *Removing allergens and reducing toxins from food crops.* Current Opinion in Biotechnology, 2009. 20(2): p. 191-196.

44. Besler, M., H. Steinhart, and A. Paschke, *Stability of food allergens and allergenicity of processed foods.* Journal of Chromatography B: Biomedical Sciences and Applications, 2001. 756(1–2): p. 207-228.

45. Thomas, K., et al., *Evaluating the effect of food processing on the potential human allergenicity of novel proteins: International workshop report.* Food and Chemical Toxicology, 2007. 45(7): p. 1116-1122.

46. *DIRECTIVE 2000/13/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the approximation of the laws of the Member States relating to the labelling, presentation and advertising of foodstuffs*, H.a.C. (SANCO), Editor 2000, Publications Office of the European Union.

47. *Food Allergen Labeling and Consumer Protection Act of 2004*, U.S.D.o.H.a.H. Services, Editor 2004.

48. Kjelkevik, R., U. Edberg, and I. Malmheden Yman, *Labelling of potential allergens in food.* Environmental Toxicology and Pharmacology, 1997. 4(1–2): p. 157-162.

49. Xiu, C. and K.K. Klein, *Melamine in milk products in China: Examining the factors that led to deliberate use of the contaminant.* Food Policy, 2010. 35(5): p. 463-470.

50. Pieretti, M.M., et al., *Audit of manufactured products: Use of allergen advisory labels and identification of labeling ambiguities.* Journal of Allergy and Clinical Immunology, 2009. 124(2): p. 337-341.

51. *Food Industry Guide to the Voluntary Incidental Trace Allergen Labelling (VITAL) Program Version 2.0*. [PDF] 2012 [cited 2013 23 October]; Available from: http://www.allergenbureau.net/downloads/vital/VITAL-Guidance-document-15-May-2012.pdf.

52. Ward, R., et al., *A vision for allergen management best practice in the food industry.* Trends in Food Science & Technology, 2010. 21(12): p. 619-625.

53. Cornelisse-Vermaat, J.R., et al., *The information needs and labelling preferences of food allergic consumers: the views of stakeholders regarding information scenarios.* Trends in Food Science & Technology, 2008. 19(12): p. 669-676.

54. Saulo, A.A. and H.R. Moskowitz, *Uncovering the mind-sets of consumers towards food safety messages.* Food Quality and Preference, 2011. 22(5): p. 422-432.

55. Cheftel, J.C., *Food and nutrition labelling in the European Union.* Food Chemistry, 2005. 93(3): p. 531-550.

56. Verbeke, W., et al., *Why consumers behave as they do with respect to food safety and risk information.* Analytica Chimica Acta, 2007. 586(1–2): p. 2-7.

57. Joshi, P., S. Mofidi, and S.H. Sicherer, *Interpretation of commercial food ingredient labels by parents of food-allergic children.* Journal of Allergy and Clinical Immunology, 2002. 109(6): p. 1019-1021.

58. Bánáti, D., *Consumer response to food scandals and scares.* Trends in Food Science & Technology, 2011. 22(2–3): p. 56-60.

59. Marucheck, A., et al., *Product safety and security in the global supply chain: Issues, challenges and research opportunities.* Journal of Operations Management, 2011. 29(7–8): p. 707-720.

60. Gorris, L.G.M., *Food safety objective: An integral part of food chain management.* Food Control, 2005. 16(9): p. 801-809.

61. Bai, L., et al. *Costs and benefits of implementing and operating HACCP in the Chinese food enterprises*. in *5th International Conference on Bioinformatics and Biomedical Engineering, iCBBE 2011, May 10, 2011 - May 12, 2011*. 2011. Wuhan, China: IEEE Computer Society.

62. Kato, S., et al., *Japan's trial introduction of HACCP into water quality management.* Water 21, 2006(DEC.): p. 39-40.

63. Khalid, A.N. *Exploring the HACCP teams in Dubai hotel sector*. in *SPE Middle East Health, Safety, Security, and Environment Conference and Exhibition 2012: Sustaining World Energy Through an Integrated HSSE and Business Approach, MEHSSE, April 2, 2012 - April 4, 2012*. 2012. Abu Dhabi, United arab emirates: Society of Petroleum Engineers.

64. Marnellos, G. and G. Tsiotras, *Hazard Analysis Critical Control Point (HACCP): Implementation in Greek industry.* Quality and Reliability Engineering International, 1999. 15(5): p. 385-396.

65. Martin, R.E., *HACCP: Present and future implications for U.S. seafood industries and regulatory agencies.* Journal of Aquatic Food Product Technology, 1998. 7(3): p. 5-27.

66. Sheth, M., R. Gurudasani, and R. Mudbidri, *Screening for pathogenic microorganisms in street-vended bhelpuri in urban Vadodara: A HACCP approach.* Journal of Food Science and Technology, 2005. 42(5): p. 395-399.

67. Friis, A. and B.B.B. Jensen, *Prediction of Hygiene in Food Processing Equipment Using Flow Modelling.* Food and Bioproducts Processing, 2002. 80(4): p. 281-285.

68. Bénézech, T., et al., *A new test method for in-place cleanability of food processing equipment.* Journal of Food Engineering, 2002. 54(1): p. 7-15.

69. *A method for assessing the in-place cleanability of food-processing equipment.* Trends in Food Science & Technology, 2007. 18, Supplement 1(0): p. S54-S58.

70. Fryer, P.J. and K. Asteriadou, *A prototype cleaning map: A classification of industrial cleaning processes.* Trends in Food Science & Technology, 2009. 20(6–7): p. 255-262.

71. Burfoot, D., et al., *Generation and dispersion of droplets from cleaning equipment used in the chilled food industry.* Journal of Food Engineering, 2003. 58(4): p. 343-353.

72. Grayson, W. and S. Morgan, *Cleaning to remove allergens -the basic principles.* Food Science and Technology, 2010. 24(3): p. 45-46.

73. Abdulmalek, F.A. and J. Rajgopal, *Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study.* International Journal of Production Economics, 2007. 107(1): p. 223-236.

74. Mehrotra, M., et al., *Production planning with patterns: A problem from processed food manufacturing.* Operations Research, 2011. 59(2): p. 267-282.

75. Yee, K.L. and N. Shah, *Scheduling of Multistage Fast-Moving Consumer Goods Plants.* The Journal of the Operational Research Society, 1997. 48(12): p. 1201-1214.

76. Zugarramurdi, A., et al., *A quality cost model for food processing plants.* Journal of Food Engineering, 2007. 83(3): p. 414-421.

Appendix A

Operator data

Times worked by individual operators for Monday 03-02-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:30	13:00			Staff count	19
Operator 1	13:30	16:15	7:55		Away	1
Operator 2	7:32	12:38			Working	18
Operator 2	13:10	16:17	7:55			
Operator 3	7:26	12:45			Max time	16:15:00
Operator 3	13:16	16:16	8:00		Start time	6:00:00
Operator 4	7:30	12:30			Tot Prod Time	10:15:00
Operator 4	13:00	16:15	7:55			
Operator 5					Lunch	0:50:00
Operator 6	7:37	12:38				
Operator 6	13:15	16:13	7:46			
Operator 7	7:37	12:38			Sum_hrs	142:47:00
Operator 7	13:15	16:13	7:46			
Operator 8	6:49	12:31			Avg_hrs/LabourUnit	7:55:57
Operator 8	13:03	15:59	8:20			
Operator 9	7:30	16:00	7:40		Volume	7788
Operator 10	5:57	12:50				
Operator 10	13:21	15:16	8:29			
Operator 11	5:57	12:44				
Operator 11	13:14	15:57	9:10			
Operator 12	7:22	12:53				
Operator 12	13:18	16:09	7:57			
Operator 13	7:25	12:44				
Operator 13	13:14	16:12	7:57			
Operator 14	9:03	12:42				
Operator 14	13:16	14:26	4:33			
Operator 15	7:29	12:37				
Operator 15	13:12	16:12	7:53			
Operator 16	5:56	12:42				
Operator 16	13:12	15:55	9:09			
Operator 17	7:34	12:45				
Operator 17	13:16	17:40	9:16			
Operator 18	7:27	12:44				
Operator 18	13:15	16:09	7:52			
Operator 19	3:50	6:22				
Operator 19	8:48	14:20	7:14			

Times worked by individual operators for Monday 03-03-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:29	12:28			Staff count	21
Operator 1	12:56	15:19	7:00		Away	2
Operator 2					Working	19
Operator 3	7:25	12:23				
Operator 3	12:53	15:22	7:07		Max time	15:22:00
Operator 4	7:30	12:30			Start time	6:00:00
Operator 4	13:00	16:00	7:40		Tot Prod Time	9:22:00
Operator 5	7:25	12:50				
Operator 5	13:18	15:22	7:07		Lunch/Tea	0:50:00
Operator 6	7:29	12:23				
Operator 6	12:52	15:19	7:00			
Operator 7	7:30	12:30			Sum_hrs	132:50:00
Operator 7	13:00	16:00	7:40			
Operator 8	7:27	12:51			Avg_hrs/LabourUnit	7:22:47
Operator 8	13:19	15:19	7:02			
Operator 9	7:30	12:23			Volume	5806
Operator 10	12:52	15:19	6:59			
Operator 11						
Operator 12	7:24	16:36	8:22			
Operator 13	5:57	12:50				
Operator 13	13:17	14:29	7:42			
Operator 14	5:58	12:50				
Operator 14	13:18	14:29	7:41			
Operator 15	7:24	12:46				
Operator 15	13:14	16:31	8:17			
Operator 16	7:28	12:25				
Operator 16	12:54	15:19	7:01			
Operator 17	7:42	12:50				
Operator 17	13:17	14:28	5:56			
Operator 18	5:57	12:29				
Operator 18	12:59	14:30	7:43			
Operator 19	7:25	12:52				
Operator 19	13:18	15:21	7:06			
Operator 20	7:24	12:52				
Operator 20	13:22	16:31	8:17			
Operator 21	4:00	6:30				
Operator 21	8:30	14:00	7:10			

Times worked by individual operators for Monday 10-03-14

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:28	12:40			Staff count	21
Operator 1	13:10	15:56	7:38		Away	2
Operator 2					Working	19
Operator 3	7:24	12:36				
Operator 3	13:06	16:00	7:46		Max time	16:00:00
Operator 4	7:30	12:30			Start time	6:00:00
Operator 4	13:00	16:00	7:40		Tot Prod Time	10:00:00
Operator 5	7:24	12:49				
Operator 5	13:20	15:57	7:43		Lunch/Tea	0:50:00
Operator 6	7:24	12:53				
Operator 6	13:23	16:04	7:50			
Operator 7	7:30	12:30			Sum_hrs	145:42:00
Operator 7	13:00	16:00	7:40			
Operator 8	7:27	12:39			Avg_hrs/LabourUnit	7:40:06
Operator 8	13:09	15:55	7:38			
Operator 9	7:28	12:36			Volume	6746
Operator 9	13:07	15:56	7:38			
Operator 10						
Operator 11	7:26	17:17	9:01			
Operator 12	5:58	12:36	6:38			
Operator 13	13:07	16:08	9:20			
Operator 14	5:57	12:49				
Operator 14	13:20	15:57	9:10			
Operator 15	7:24	12:47				
Operator 15	13:17	15:02	6:48			
Operator 16	7:36	12:37				
Operator 16	13:07	16:06	7:40			
Operator 17	8:45	12:36				
Operator 17	13:07	14:16	4:41			
Operator 18	5:57	12:37				
Operator 18	13:07	15:55	9:08			
Operator 19	7:24	12:49				
Operator 19	13:20	13:29	5:15			
Operator 20	7:23	12:47				
Operator 20	13:17	15:56	7:43			
Operator 21	3:45	6:27				
Operator 21	7:28	14:21	8:45			

Times worked by individual operators for Monday 24-03-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:26	12:18			Staff count	20
Operator 1	12:47	15:45	7:29		Away	2
Operator 2	7:25	12:21			Working	18
Operator 2	12:50	15:47	7:32			
Operator 3	7:21	12:21			Max time	15:45:00
Operator 3	12:52	15:41	7:30		Start time	6:00:00
Operator 4	6:58	12:20			Tot Prod Time	9:45:00
Operator 4	12:54	15:41	7:53			
Operator 5	7:23	12:27			Lunch	0:50:00
Operator 5	12:58	15:41	7:28			
Operator 6	7:26	12:21				
Operator 6	12:47	15:45	7:29		Sum_hrs	132:24:00
Operator 7	6:58	12:20				
Operator 7	12:57	15:41	7:53		Avg_hrs/LabourUnit	7:21:20
Operator 8	7:26	12:18	4:02			
Operator 9	7:27	12:18			Volume	5842
Operator 9	12:47	15:45	7:28			
Operator 10	7:26	12:31				
Operator 10	13:01	16:00	7:44			
Operator 11	7:25	16:00	7:45			
Operator 12	5:56	12:27				
Operator 12	12:56	15:01	8:15			
Operator 13	5:56	12:28				
Operator 13	12:57	14:27	7:41			
Operator 14	7:24	12:20				
Operator 14	12:52	15:52	7:38			
Operator 15	7:27	12:27				
Operator 15	12:58	15:43	7:26			
Operator 16						
Operator 17	5:56	12:28				
Operator 17	12:58	14:44	7:58			
Operator 18	7:25	12:27				
Operator 18	12:57	14:43	6:28			
Operator 19						
Operator 20	3:44	6:22				
Operator 20	9:21	14:18	6:45			

Times worked by individual operators for Monday 31-03-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:26	12:06			Staff count	20
Operator 1	12:35	15:12	6:56		Away	2
Operator 2	7:25	12:27			Working	18
Operator 2	12:56	15:14	6:59			
Operator 3	7:22	12:07			Max time	15:12:00
Operator 3	12:33	15:12	7:00		Start time	6:00:00
Operator 4	7:23	12:07			Tot Prod Time	9:12:00
Operator 4	12:33	15:12	6:59			
Operator 5	7:23	12:32			Lunch	0:50:00
Operator 5	13:02	15:11	6:58			
Operator 6						
Operator 7	7:26	12:05			Sum_hrs	128:44:00
Operator 7	12:33	15:15	6:59			
Operator 8	7:26	12:06			Avg_hrs/LabourUnit	7:09:07
Operator 8	12:35	15:12	6:56			
Operator 9	7:28	12:38			Volume	4829
Operator 9	13:10	15:15	6:57			
Operator 10	6:06	12:39				
Operator 10	13:06	15:23	8:27			
Operator 11	7:26	16:00	7:44			
Operator 12	5:57	12:36				
Operator 12	13:08	14:33	7:46			
Operator 13	5:54	12:31				
Operator 13	13:01	14:25	7:41			
Operator 14	7:23	12:35				
Operator 14	13:05	15:05	6:52			
Operator 15	7:27	12:39				
Operator 15	13:10	15:11	6:54			
Operator 16						
Operator 17	5:57	12:39				
Operator 17	13:10	14:37	7:50			
Operator 18	7:21	12:39				
Operator 18	13:10	15:12	7:01			
Operator 19	7:23	12:35				
Operator 19	13:05	15:05	6:52			
Operator 20	3:50	6:19				
Operator 20	9:19	13:33	5:53			

Times worked by individual operators for Monday 07-04-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	8:30	12:37			Staff count	20
Operator 1	13:05	15:45	6:25		Away	2
Operator 2	7:30	12:32			Working	18
Operator 2	13:02	15:45	7:25			
Operator 3	8:23	12:37			Max time	15:53:00
Operator 3	13:08	15:46	6:33		Start time	6:00:00
Operator 4	7:30	12:37			Tot Prod Time	9:53:00
Operator 4	13:09	15:47	7:27			
Operator 5	7:30	12:26			Lunch	0:50:00
Operator 5	12:56	15:47	7:27			
Operator 6						
Operator 7	7:30	12:39			Sum_hrs	132:19:00
Operator 7	13:08	15:45	7:25			
Operator 8	7:30	12:34			Avg_hrs/LabourUnit	7:21:03
Operator 8	13:03	15:46	7:26			
Operator 9	7:30	12:38			Volume	5336
Operator 9	13:09	15:46	7:26			
Operator 10	7:43	12:40				
Operator 10	13:09	15:46	7:13			
Operator 11	7:30	15:53	7:33			
Operator 12	6:00	12:27				
Operator 12	12:58	14:32	7:42			
Operator 13	6:00	12:28				
Operator 13	12:56	14:30	7:40			
Operator 14	7:30	12:40				
Operator 14	13:07	15:44	7:24			
Operator 15	7:30	12:40				
Operator 15	13:11	15:46	7:26			
Operator 16						
Operator 17	6:00	12:39				
Operator 17	13:11	14:36	7:46			
Operator 18	7:30	12:00				
Operator 18	12:30	15:53	7:33			
Operator 19	7:30	12:38				
Operator 19	13:07	15:30	7:10			
Operator 20	3:46	6:20				
Operator 20	8:43	14:17	7:18			

Times worked by individual operators for Monday 02-12-2013

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:30	12:30			Staff count	18
Operator 1	13:00	15:30	7:10		Away	1
Operator 2	7:29	12:08			Working	17
Operator 2	12:40	15:29	7:10			
Operator 3					Max time	15:29:00
Operator 4	7:30	12:08			Start time	6:00:00
Operator 4	12:41	15:26	7:06		Tot Prod Time	9:29:00
Operator 5	7:29	12:03				
Operator 5	12:32	15:24	7:05		Lunch/Tea	0:50:00
Operator 6	7:29	12:04				
Operator 6	12:37	15:23	7:04			
Operator 7	7:26	12:42			Sum_hrs	120:16:00
Operator 7	13:13	15:30	7:14			
Operator 8	7:25	12:10			Avg_hrs/LabourUnit	7:04:28
Operator 8	12:41	15:24	7:09			
Operator 9	7:30	16:00	7:40		Volume	4562
Operator 10	5:56	11:47				
Operator 10	12:18	14:36	7:50			
Operator 11	5:56	12:40				
Operator 11	13:11	14:36	7:50			
Operator 12	7:20	12:55				
Operator 12	13:30	15:22	7:12			
Operator 13	9:00	12:30				
Operator 13	13:00	14:25	4:35			
Operator 14	7:30	12:03				
Operator 14	12:34	15:23	7:03			
Operator 15	5:55	12:22				
Operator 15	12:55	14:36	7:51			
Operator 16	7:27	12:42				
Operator 16	13:12	15:26	7:09			
Operator 17	7:26	12:10				
Operator 17	12:39	15:22	7:06			
Operator 18	3:50	6:18				
Operator 18	9:45	14:09	6:02			

Times worked by individual operators for Monday 20-01-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:30	12:26			Staff count	18
Operator 1	12:58	15:49	7:29		Away	1
Operator 2	7:30	12:26			Working	17
Operator 2	12:57	15:49	7:29			
Operator 3	7:27	12:31			Max time	15:53:00
Operator 3	13:01	15:49	7:32		Start time	6:00:00
Operator 4	7:34	12:28			Tot Prod Time	9:53:00
Operator 4	13:00	15:49	7:25			
Operator 5	7:34	12:40			Lunch	0:50:00
Operator 5	13:13	15:49	7:25			
Operator 6	7:34	12:40				
Operator 6	13:13	15:49	7:25		Sum_hrs	126:36:00
Operator 7	7:26	12:26				
Operator 7	12:57	15:53	7:37		Avg_hrs/LabourUnit	7:26:49
Operator 8	7:27	15:53	7:36			
Operator 9	5:57	12:34			Volume	6028
Operator 9	13:04	14:31	7:44			
Operator 10	5:58	12:33				
Operator 10	13:00	14:30	7:42			
Operator 11	5:57	12:52	6:55			
Operator 12	7:29	12:33				
Operator 12	13:01	15:50	7:31			
Operator 13	7:27	12:34				
Operator 13	13:04	14:43	6:26			
Operator 14	7:30	12:34				
Operator 14	13:07	15:49	7:29			
Operator 15						
Operator 16	7:30	12:33				
Operator 16	13:01	15:52	7:32			
Operator 17	5:57	12:26				
Operator 17	12:52	14:31	7:44			
Operator 18	3:57	6:22				
Operator 18	8:30	14:30	7:35			

Times worked by individual operators for Monday 18-11-2013

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:30	12:30			Staff count	17
Operator 1	13:00	16:17	7:57:00		Away	1
Operator 2	7:25	12:30			Working	16
Operator 2	13:01	16:17	8:02:00			
Operator 3	7:30	12:30			Max time	16:27:00
Operator 3	13:00	16:15	7:55:00		Start time	6:00:00
Operator 4					Tot Prod Time	10:27:00
Operator 5	7:38	12:27				
Operator 5	13:00	16:22	7:54:00		Lunch	0:50:00
Operator 6	7:39	12:27				
Operator 6	13:00	16:17	7:48:00			
Operator 7	7:27	12:44			Sum_hrs	135:11:00
Operator 7	13:15	16:23	8:06:00			
Operator 8	7:24	12:30			Avg_hrs/LabourUnit	8:26:56
Operator 8	13:00	16:14	8:00:00			
Operator 9	5:57	16:27	9:40:00		Volume	6130
Operator 10	5:57	12:40				
Operator 10	13:10	16:15	9:28:00			
Operator 11	4:57	12:43				
Operator 11	13:15	16:23	10:36:00			
Operator 12	7:26	12:33				
Operator 12	12:59	16:12	7:56:00			
Operator 13	7:27	12:36				
Operator 13	13:03	16:14	7:57:00			
Operator 14	7:30	12:30				
Operator 14	13:00	16:15	7:55:00			
Operator 15	5:57	12:38				
Operator 15	13:08	15:56	9:09:00			
Operator 16	7:44	12:43				
Operator 16	13:15	16:23	7:49:00			
Operator 17	6:28	12:31				
Operator 17	12:57	16:17	8:59:00			

Times worked by individual operators for Monday 25-11-2013

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	8:30	12:30			Staff count	16
Operator 1	13:00	15:50	6:30		Away	0
Operator 2	7:29	12:22			Working	16
Operator 2	12:53	15:48	7:29			
Operator 3	7:29	12:21			Max time	15:47:00
Operator 3	12:52	15:47	7:28		Start time	6:00:00
Operator 4	7:38	12:22			Tot Prod Time	9:47:00
Operator 4	12:52	15:47	7:19			
Operator 5	7:39	12:22			Lunch	0:50:00
Operator 5	12:52	15:48	7:19			
Operator 6	7:39	12:22				
Operator 6	12:53	15:47	7:18		Sum_hrs	116:48:00
Operator 7	7:27	12:34				
Operator 7	13:06	16:00	7:43		Avg_hrs/LabourUnit	7:18:00
Operator 8	7:25	12:31				
Operator 8	13:03	15:46	7:31		Volume	4652
Operator 9	7:21	16:00	7:49			
Operator 10	5:58	12:23				
Operator 10	12:52	14:32	7:44			
Operator 11	4:59	12:25				
Operator 11	12:55	14:32	8:43			
Operator 12	7:21	12:23				
Operator 12	12:44	15:46	7:35			
Operator 13	8:51	12:20	2:39			
Operator 14	7:28	12:21				
Operator 14	12:53	15:47	7:29			
Operator 15	5:59	12:31				
Operator 15	13:03	14:32	7:43			
Operator 16	7:27	12:31				
Operator 16	13:03	16:46	8:29			

Times worked by individual operators for Monday 27-01-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:30	12:30			Staff count	19
Operator 1	13:00	15:18	6:58		Away	3
Operator 2	7:32	12:26			Working	16
Operator 2	12:57	15:21	6:59			
Operator 3					Max time	15:20:00
Operator 4	7:30	12:30			Start time	6:00:00
Operator 4	13:00	15:30	7:10		Tot Prod Time	9:20:00
Operator 5	7:37	12:26				
Operator 5	12:57	15:18	6:51		Lunch	0:50:00
Operator 6	7:38	12:28				
Operator 6	13:01	15:19	6:51			
Operator 7	7:38	12:27			Sum_hrs	111:53:00
Operator 7	13:01	15:19	6:51			
Operator 8	5:56	6:58			Avg_hrs/LabourUnit	6:59:34
Operator 8	13:02	15:20	8:34			
Operator 9	7:24	16:00	7:46		Volume	5450
Operator 10						
Operator 11	5:59	12:32				
Operator 11	13:01	14:37	7:48			
Operator 12	5:57	12:33				
Operator 12	13:01	14:32	7:45			
Operator 13	7:26	12:32				
Operator 13	13:01	15:18	7:02			
Operator 14	7:34	12:31				
Operator 14	12:59	14:29	6:05			
Operator 15	9:51	12:25				
Operator 15	12:57	15:19	4:38			
Operator 16						
Operator 17	7:35	12:33				
Operator 17	13:02	15:18	6:53			
Operator 18	7:23	12:33				
Operator 18	13:01	15:13	7:00			
Operator 19	3:52	6:20				
Operator 19	8:15	13:19	6:42			

Times worked by individual operators for Monday 17-02-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:28	12:14			Staff count	17
Operator 1	12:43	15:56	7:38		Away	1
Operator 2	7:27	12:14			Working	16
Operator 2	12:42	15:56	7:39			
Operator 3	7:24	12:13			Max time	16:23:00
Operator 3	12:43	15:57	7:43		Start time	6:00:00
Operator 4	7:30	12:30			Tot Prod Time	10:23:00
Operator 4	13:00	16:00	7:40			
Operator 5	7:28	12:15			Lunch	0:50:00
Operator 5	12:43	15:56	7:38			
Operator 6	7:29	12:15				
Operator 6	12:43	15:56	7:37		Sum_hrs	129:19:00
Operator 7	7:26	12:14				
Operator 7	12:43	15:57	7:41		Avg_hrs/LabourUnit	8:04:56
Operator 8						
Operator 9	5:56	12:02			Volume	5894
Operator 9	12:35	16:29	9:43			
Operator 10	5:02	12:43				
Operator 10	13:07	16:29	10:37			
Operator 11	5:51	12:01				
Operator 11	12:29	16:31	9:50			
Operator 12	7:27	12:16				
Operator 12	12:44	15:56	7:39			
Operator 13	8:45	12:38				
Operator 13	13:06	14:26	4:51			
Operator 14	4:55	12:30				
Operator 14	12:59	16:29	10:44			
Operator 15	8:07	12:44				
Operator 15	13:07	16:23	7:26			
Operator 16	7:28	12:38				
Operator 16	13:08	16:23	8:05			
Operator 17	3:46	6:24				
Operator 17	9:21	14:21	6:48			

Times worked by individual operators for Monday 14-04-2014

SHORTNAME	STARTDATETIME	ENDDATETIME	TIMEWORKED			
Operator 1	7:27	12:48			Staff count	20
Operator 1	13:17	16:00	7:43		Away	4
Operator 2	7:27	13:00			Working	16
Operator 2	13:27	15:45	7:28			
Operator 3	7:23	12:48			Max time	15:45:00
Operator 3	13:17	15:45	7:32		Start time	6:00:00
Operator 4					Tot Prod Time	9:45:00
Operator 5	7:22	12:52				
Operator 5	13:19	15:45	7:33		Lunch	0:50:00
Operator 6	7:26	12:48				
Operator 6	13:17	15:45	7:29			
Operator 7					Sum_hrs	123:04:00
Operator 8	7:27	12:47				
Operator 8	13:17	15:45	7:28		Avg_hrs/LabourUnit	7:41:30
Operator 9	7:27	12:53				
Operator 9	13:23	15:45	7:28		Volume	6905
Operator 10	6:20	12:49				
Operator 10	13:18	16:00	8:50			
Operator 11	5:57	16:04	9:17			
Operator 12	5:57	12:49				
Operator 12	13:17	15:13	8:26			
Operator 13	5:56	12:52				
Operator 13	13:19	14:24	7:38			
Operator 14	7:23	13:00				
Operator 14	13:24	15:40	7:27			
Operator 15	7:26	12:54				
Operator 15	13:23	15:45	7:29			
Operator 16						
Operator 17	5:57	12:53				
Operator 17	13:23	14:41	7:54			
Operator 18	7:25	12:53				
Operator 18	13:23	14:57	6:42			
Operator 19						
Operator 20	3:43	6:19				
Operator 20	9:21	14:15	6:40			

Appendix B

Allergen control data

Allergen content of products produced on process line A5/B1

Product Code	Component Code	Gluten	Soy	Milk	Egg	Tree Nuts	Sesame	Sulphites	No Allergen
230204	440200								
	447848								
									x
733736	440080								
	447848								
									x
750368	440200								
	447848								
									x
750375	440200								
	447848								
									x
750443	440375		x						
	447848								
			x						
750726	440375		x						
	447848								
			x						
230471	440375		x						
	447848								
			x						
230730	441063		x					x	
	447848								
			x					x	
330133	440061		x						
	440818							x	
	447848								
			x					x	
730070	440061								
	440818								
	447848								
			x					x	
750832	441063		x					x	
	447848								
			x					x	

Allergen content of products produced on process line A6/C2/D1

Product Code	Component Code	Gluten	Soy	Milk	Egg	Tree Nuts	Sesame	Sulphites	No Allergen
460915	440170							x	
	440415								
	441073								
	449071	x							
		x						x	
461011	440170							x	
	440415								
	441073								
	449071	x							
		x						x	
461035	440877		x	x					
	449071	x							
	449116			x					
		x	x	x					
461110	440877		x	x					
	449071	x							
	449116			x					
		x	x	x					
461622	441992	x	x					x	
	449071	x							
	449116			x					
		x	x	x				x	
461721	441992	x	x					x	
	449071	x							
	449116			x					
		x	x	x				x	
460038	440041		x					x	
	449071	x							
	449116			x					
		x	x	x				x	
460939	440041		x					x	
	449071	x							
	449116			x					
		x	x	x				x	

Allergen content of products produced on process line A4/C1/D1

Product Code	Component Code	Gluten	Soy	Milk	Egg	Tree Nuts	Sesame	Sulphites	No Allergen
460229	440640	x							
	447306	x							
	447848								
	449005								
		x							
461233	440640	x							
	447306	x							
	447848								
	449005								
		x							
461738	447306	x							
	447411	x							
	447848								
	449005								
		x							
730339	440640	x							
	447306	x							
	447848								
	449005								
		x							
461301	440027								
	440640	x							
	440707		x						
	447306	x							
	447848								
	449005								
		x	x						
461325	440027								
	440138	x		x					
	440640	x							
	447306	x							
	447848								
	449005								
		x		x					
460694	440027								
	440138	x		x					
	440640	x							
	447306	x							
	447848								
	449005								
		x		x					
461202	440027								
	440640	x							
	440967			x					
	447306	x							
	447848								
	449005								
		x		x					

Allergen content of products produced on process line A4/C1/D1 (Continued)

461219	440027								
	440640	x							
	440967			x					
	447306	x							
	447848								
	449005								
		x		x					
461226	440027								
	440640	x							
	440807	x	x	x					
	447306	x							
	447848								
	449005								
		x	x	x					
461424	440027								
	440640	x							
	441007		x	x					
	447306	x							
	447848								
	449005								
		x	x	x					
460670	440027								
	440640	x							
	441007		x	x					
	447306	x							
	447848								
	449005								
		x	x	x					
	440640	x							
	440807	x	x	x					
	447306	x							
	447848								
	449005								
		x	x	x					
461127	440027								
	440137			x		x		x	
	440640	x							
	447306	x							
	447848								
	449005								
		x		x		x		x	
230969	440027								
	440137			x		x		x	
	440640	x							
	447306	x							
	447848								
	449005								
		x		x		x		x	
460663	440027								
	440137			x		x		x	
	440640	x							
	447306	x							
	447848								
	449005								
		x		x		x		x	

Allergen content of products produced on process line B2/C2/D1

Product Code	Component Code	Gluten	Soy	Milk	Egg	Tree Nuts	Sesame	Sulphites	No Allergen
750023	440027								
	447848								
bulk									x
682546	441077							x	
								x	
682904	442283							x	
								x	
683086	440754	x						x	
		x						x	
681709	440754	x						x	
		x						x	
682553	440780	x	x					x	
		x	x					x	
682584	441249	x	x					x	
		x	x					x	
682591	441249	x	x					x	
		x	x					x	
682690	441249	x	x					x	
		x	x					x	
682706	440991	x	x					x	
		x	x					x	
682799	440571	x	x					x	
		x	x					x	
682805	440971	x	x					x	
		x	x					x	
682898	440571	x	x					x	
		x	x					x	
750160	440780	x	x					x	
bulk		x	x					x	
750306	441249	x	x					x	
bulk		x	x					x	
680061	440780	x	x					x	
	441249	x	x					x	
		x	x					x	
681402	441249	x	x					x	
		x	x					x	
681501	440780	x	x					x	
		x	x					x	
681549	441249	x	x					x	
		x	x					x	
681648	440780	x	x					x	
		x	x					x	

Allergen content of products produced on process line B2

Product Code	Component Code	Gluten	Soy	Milk	Egg	Tree Nuts	Sesame	Sulphites	No Allergen
579242	442233								
									x
579648	442233								
									x
730063	446971							x	
								x	
734504	447009	x						x	
		x						x	
579341	442253	x							
		x							
579440	442243	x	x						
		x	x						
579549	442243	x	x						
		x	x						
579143	442263	x	x						
		x	x						